Sewage Research

EXPERIMENTAL STUDIES OF BIO-FILTRATION

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Synopsis

Current sanitary engineering practice favors one or the other of two methods of sewage treatment involving biologic oxidation, as embodied in the trickling filter and in the activated-sludge process.

Studies of biologic oxidation in its broader aspects warrant the conclusion that the aerating effect of allowing sewage to traverse a stretch of flow of considerable length a single time, such as occurs in the self-purification of natural streams, may be accomplished equally well by subjecting the sewage to repeated passages of flow over stretches of relatively short length. This stream-flow principle has found noteworthy practical application in the bio-aeration plants of the Sheffield (England) type, where recirculation through approximately one mile of channel length is maintained by mechanical means, while the sewage proceeds through the treatment works.

The author has determined that similar results may be obtained by repeatedly passing the sewage or organic wastes through a relatively small volume of biologic filtering material rather than allowing it to percolate through a larger volume of rock but once, as in the conventional trickling filter.

This principle of recirculation results in a process of bio-filtration by means of which it appears possible to combine in a single form of treatment the major advantages of the activated-sludge process and of the trickling filter (bacteria bed), and at the same time to obviate the more serious shortcomings of either method.

The following paper is intended as a preliminary statement and discussion of data and conclusions obtained principally in the operation of two experimental bio-filter plants in California, designed by the author for Orange County (Fig. 1) and for the City of Salinas (Fig. 2).

One of the purposes of the Orange County installation, located in the City of Santa Ana, was to investigate the possibility of reclaiming irrigation water from the sewage now discharged to the Pacific Ocean through the Orange County joint outfall sewer system. The Salinas plant has served to determine the most satisfactory method of treating a difficult municipal sewage. The Orange County plant was designed in 1933, constructed during 1934 and operated during 1934 and 1935. The Salinas studies were initiated in 1934, have been carried on continuously to the present time, and are still in progress.

The Orange County investigations were concerned chiefly with a

determination of specific engineering design factors for a full-scale treatment works for the particular sewage under test. It was found that two-stage bio-filtration was successful in producing consistently an effluent of the required high degree of oxidation, stability and clarity. The Salinas research has extended considerably beyond the immediate objectives of the work, in order to include a comprehensive quantitative study of the underlying elements of bio-filtration.

The author is indebted to the City of Salinas for their authorization of this work, and to Donald Davies, Jr., City Engineer, for his active

FIG. 1.—Orange County (Calif.) water reclamation experimental-demonstration plant.

(*A*) View showing primary detention-settling tank and bio-filter, with recirculation pumping equipment in cabinet between; followed by second-stage portable bio-filter unit (left foreground).

(*B*) General arrangement of treatment units, with covered separate sludge digestion tank and open sludge-drying bed in foreground. Note pair of funnels beyond digester, receiving sludge from detention-settling tank, for either return to bio-filter or discharge to digester.

interest and cooperation at all times. Acknowledgment should also be made of the thorough and efficient work done by Vincent Maghetti, Chemist in charge of operation of the Salinas sewage treatment plant, who has made all the laboratory determinations and has kept the experimental plant operating records.

Bio-Filtration Plant Elements

Process Designation.—It has seemed appropriate to designate as a "bio-filter" a trickling filter wherein recirculation is employed. Similarly, the term "bio-filtration" indicates a process of biologic treatment on a coarse-grained filter involving the principle of recirculation.

Method of Operation.—It will be noted from Figs. 1 and 2 that a bio-filter plant embraces a combination of a detention-settling tank and a trickling filter, between which the sewage is recirculated by means of a suitable pump.

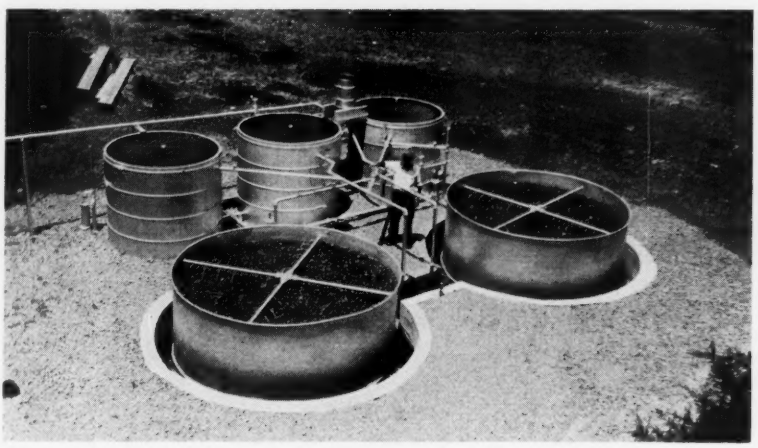

Fig. 2.—Experimental two-stage bio-filter plant, Salinas, California.

View showing general arrangement of plant units. Note coarse rock in primary bio-filter (right), with fine rock in secondary bed (left). Combined detention-settling tanks in background, with settled sewage influent line immediately beyond.

Recirculation pumps may be seen at ground level between filter units, with recirculation pipe system interconnecting these with the detention tanks.

The hydraulic flow through the plant is successively by gravity and by pumping, in accordance with two general types of recirculation. One of these involves gravity flow from the detention tank through the bio-filter, with a pumped return to the detention tank, as illustrated by the Orange County and the Salinas experimental installations. A more usual arrangement for full-scale plant designs would probably be where the bio-filter is constructed above ground level, with gravity flow into the detention tank at ground level, and pumped return through the rotary distributor onto the bio-filter bed.

Depth of Bio-Filter Bed.—Investigations of the behavior and operating efficiency of relatively shallow bio-filters have proven the practicability of using beds of but three feet and less in depth, with consequent decrease in the static head against which the recirculation pumping equipment is called upon to operate.

Originally the author conducted experiments on beds of but one foot in depth. Subsequently at the University of North Carolina, the author made tests with beds of 3-ft. and 6-ft. depth. Fig. 3 shows a

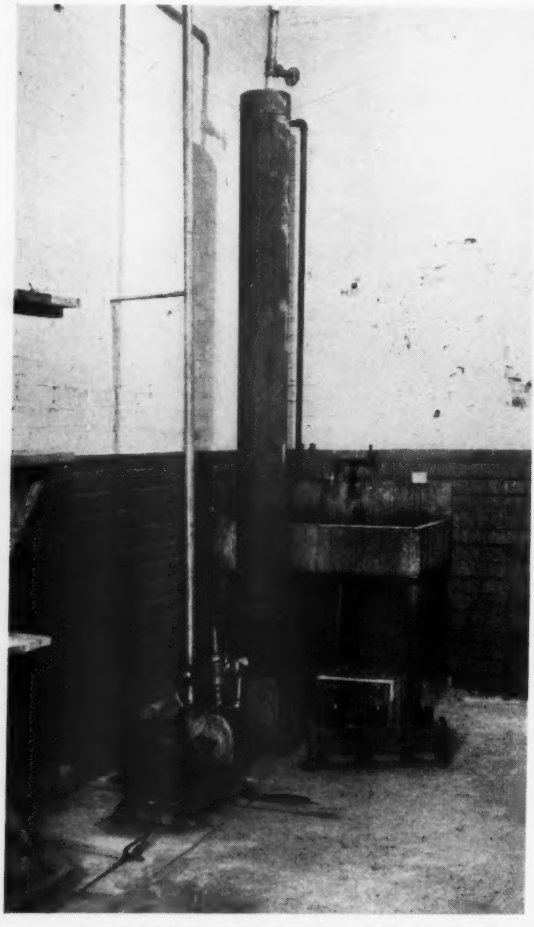

FIG. 3.—Laboratory experimental bio-filter (University of North Carolina Research, 1932). Arranged for batch operation, in studies of the applicability of bio-filtration in the treatment of textile wastes and of municipal sewage.

laboratory bio-filter of the latter depth employed for some time by the engineering department in research studies in the treatment of textile wastes and of domestic sewage. Typical purification results with Chapel Hill sewage are indicated by the curve of Fig. 4.

The advantages of a bed of conventional depth were not sufficiently apparent to warrant, in the author's opinion, its adoption in place of the shallower depths for the succeeding experimental investigations described in this paper. The relationship between filter depths and purification, both in the absolute sense, and in terms of unit purifying capacity per cubic yard of filtering material, is the subject of continued study.

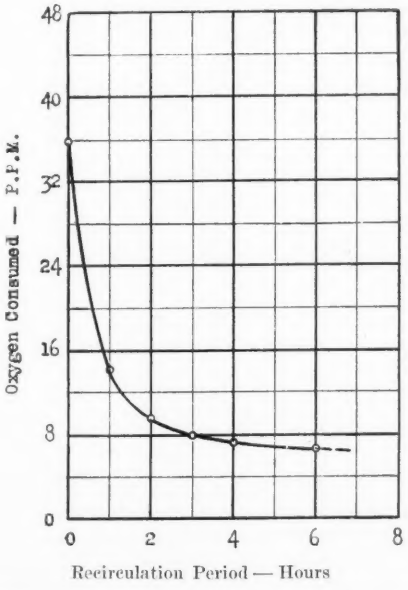

FIG. 4.—Diagram showing progressive purification of sewage by means of a laboratory bio-filter (University of North Carolina Research, 1932).

Experimental conditions: Average results of batch treatment of settled sewage, comprising institutional and domestic flow as received by Chapel Hill, N. C., sewage treatment plant. Filtering material, ½ in. to 1 in. cinders. Filter bed depth, 6 ft. Recirculation rate, 40 m.g.a.d.

Oxygen consumed by 30-minute boiling with permanganate, Standard Methods, A. P. H. A.

From the standpoint of construction cost, the shallower the bed the less the capital investment, particularly if comparable rates of filtration are permissible. The shallower depths of filter bed also admit the use of substantially finer medium than in the trickling filter, because of the more adequate ventilation in a shallow bed. This is especially true of stage-treatment, involving coarse rock in the primary bio-filter and fine rock in the secondary unit.

Combination of Sedimentation with Detention.—A functional distinction between the aeration tank of the activated-sludge process and the detention tank of the bio-filter plant arises from the fact that in the former case the oxygen demand of the sewage is satisfied by the introduction of air into the tank, while in bio-filtration the sewage is alter-

nately removed from and returned to the detention tank, the active zone of oxidation being in an adjacent biologic filter bed.

The function of aeration is thus divorced from that of detention and the function of sedimentation is combined therewith. Practically the entire power input assumes the form of a pumping load.

The Recirculation System.—The rates of recirculation between the detention tank and the bio-filter bed, as recorded hereinafter, include the flow of sewage through the plant. It appears logical to express the volume of recirculation, which is the actual quantity of liquid to be pumped, in convenient hydraulic units, such as gallons per minute (g.p.m.), or as a rate of filtration in million gallons per acre per day (m.g.a.d.). The recirculation rate is designated as "Re," while the flow of sewage itself is recorded as "Q" (in terms of g.p.m.), or as "F" (in terms of m.g.a.d.).

Recirculation is maintained by means of pumping equipment. It is clearly an advantage, from the standpoint of plant design and subsequent dependability of operation, that a standard, large capacity, low-head, screw or propeller pumping unit becomes the "heart," so to speak, of the bio-filter plant.

Functional Characteristics as Experimentally Determined

Laboratory Control.—The oxygen consumed determination has been used as a control test for defining the factors of operation of the bio-filtration process. Collateral laboratory tests, such as relative stabilities and periodic biochemical oxygen demand determinations, have served throughout the experiments to confirm the reliability of the oxygen consumed results and the conclusions derivable therefrom. The correlation obtained between oxygen consumed and biochemical oxygen demand is shown by the curve of Fig. 5.

The settled sewage has, in all cases, been taken as the basis of reference rather than the raw sewage. This has been mainly on account of the fact that the Salinas raw sewage exhibits wide fluctuations, while results of analysis of the settled sewage are relatively uniform.

It should be noted that in all experimental results recorded in the accompanying tables and diagrams, the percentages of removal of biochemical oxygen demand and oxygen consumed relate to settled sewage influent to the bio-filter plant. The over-all purification, as customarily reported, and based on the strength of the raw sewage, would accordingly be substantially greater.

Operation of the Bio-Filter

Oxidizing Capacity.—The oxidizing capacity of the bio-filter is extraordinarily augmented by recirculation and, to a significant extent (as shown in Fig. 6) is rendered independent of the physical dimensions governing the volume of rock in the filter bed. The influence of the factor of recirculation in this respect is subsequently discussed.

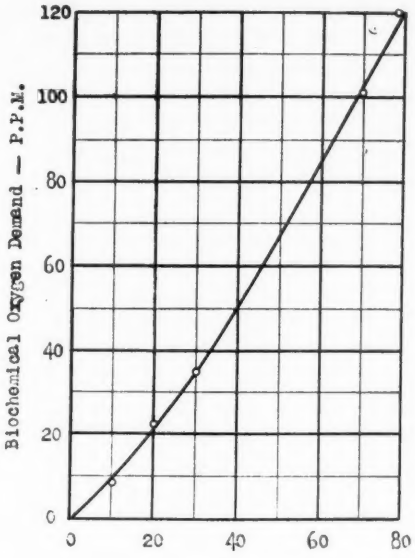

FIG. 5.—Correlation of oxygen consumed and biochemical oxygen demand. (Based on simultaneous test values derived from samples covering period July-November, 1935, Salinas, Calif., sewage treatment research.)

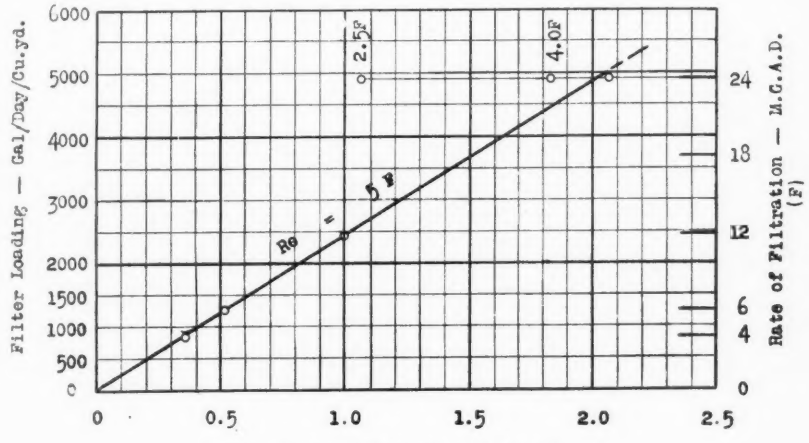

FIG. 6.—Relationship between bio-filter loading and purification, for a given value of recirculation rate.

Curve indicative of the possibility that, by maintaining a constant relationship between the rate of recirculation (Re) and that of filtration (F), an effluent of substantially uniform quality may be ensured, throughout a wide range of rate of sewage application to the bio-filter bed.

Similarities to Activated Sludge Treatment.—The behavior of the bio-filter and of the process as a whole is analogous to the activated sludge process, as attested by the fact that the typical curve of biochemical oxygen demand satisfaction is similar in both cases. Each process accomplishes a progressive purification with time, very rapidly at the beginning and diminishing as the end of the period of treatment is reached, as illustrated in Figs. 4 and 7.

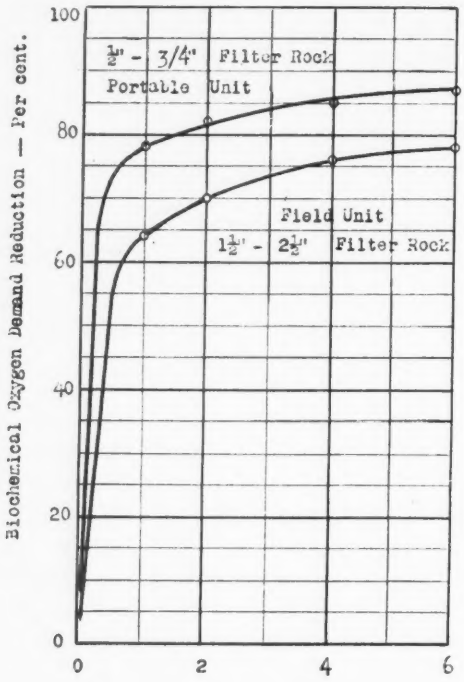

FIG. 7.—Progressive purification with time.

Curves showing relationship between recirculation period and reduction in biochemical oxygen demand, for two sizes of bio-filter rock.*

Constant Factors

Bio-Filter Unit	Detention Tank Gallons	Filter Rock Cu. yd.	Sewage Application Gal./day/cu. yd. Based on Period		Equivalent Continuous-Flow Factors	
			6-hr.	2-hr.	Rate of Filtration M.G.A.D	O.C. Removal Lb./day/cu.yd. ¶
Portable	60	0.35	685	2 055	10	0.82
Field	600	8.73	275	825	4	0.26

* Based on batch treatment.

¶ Cf. values for this factor shown in Table I.

By direct comparison with the operation of the Salinas municipal activated sludge plant, it has also been found that the period of recirculation in the experimental bio-filter plant is analogous to the period of aeration with activated sludge. For example, other conditions being equal, a sewage requiring 6 hours' aeration with activated sludge will generally require 6 hours' recirculation through a system of bio-filters, to produce a final effluent of comparable physical and biochemical characteristics.

Volume and Disposition of Filter Material.—As compared with the conventional trickling filter, the filtering medium of the bio-filter may be worked at greatly increased rates per cubic yard of rock. Conversely, for a given poundage of biochemical oxygen demand removal, the volume of bio-filter rock may become of relatively small magnitude. In view of the permissible rates, both of filtration and of recirculation, coming within the scope of the Salinas tests, it appears that the bio-filter is capable of handling sewage at high rates of application to the beds, hitherto unattempted in practice. (See Table I).

TABLE I.—*Analysis of Single-Stage Bio-Filtration in Relation to Filter Loading and Purification Effected*

Rate of Filtration (F) M.G.A.D.	Rate of Recirculation (Re)		Rate of Sewage Application to Bio-Filter Gal./day/cu. yd.	Oxygen Consumed			
	Ratio Re/F	Actual M.G.A.D.		Settled Sewage	Bio-Filter Effluent	Per cent. Reduction	Removal Lb./day/cu. yd.
4	5	20	820	74.4	22.2	70.5	0.36
6	5	30	1 230	74.8	24.5	67.3	0.52
12	5	60	2 460	76.1	27.5	63.8	1.00
18	6	108	3 690	79.5	30.5	61.8	1.51
24	5	120	4 920	78.2	28.0	64.2	2.07
24	4	96	4 920	75.8	30.8	59.4	1.84
24	2.5	60	4 920	72.3	37.7	48.0	1.06

Conditions of Operation

Continuous-flow treatment of settled sewage effluent from primary clarifier of Salinas, Calif., municipal sewage works.

Average duration of test runs at each rate of filtration, 5 days.

Oxygen consumed results are median values of twice-daily samples during corresponding test periods.

Various rates of filtration obtained by changing rates of flow through the bio-filter plant, but chiefly by application of the sewage over appropriate number of zones within the bio-filter bed area.

Constant factors: Filter bed depth, 3 ft.; rock size, 1½″–2½″. Detention period, 2 hours.

In two-stage treatment (Fig. 8) the actual disposition of a given total volume of filtering material between the primary and secondary bio-filter beds will probably depend largely on economic considerations relating to structural design and operating costs.

This conclusion is based on the data of Table II, plotted in the curve of Fig. 9. From this diagram it is apparent that, within the range

TABLE II.—*Influence on Purification Exerted by Various Relative Volumes of Rock, in Stage-Treatment by Bio-Filtration*

Run No.	Total Cubic Yards Filter Material	Bio-Filter Rock Volume Cu. yd. Primary / Cu. yd. Secondary	Over-All Oxygen Consumed Removal Lb./day/cu. yd.
3	11.64	3	0.326
5	11.64	1	0.318
7	11.64	0.33	0.297

Notes

The foregoing data were derived incidentally from Test Series A, Salinas, Calif., bio-filtration research.

See Fig. 9 for expression of results of Table 4 in graphic form.

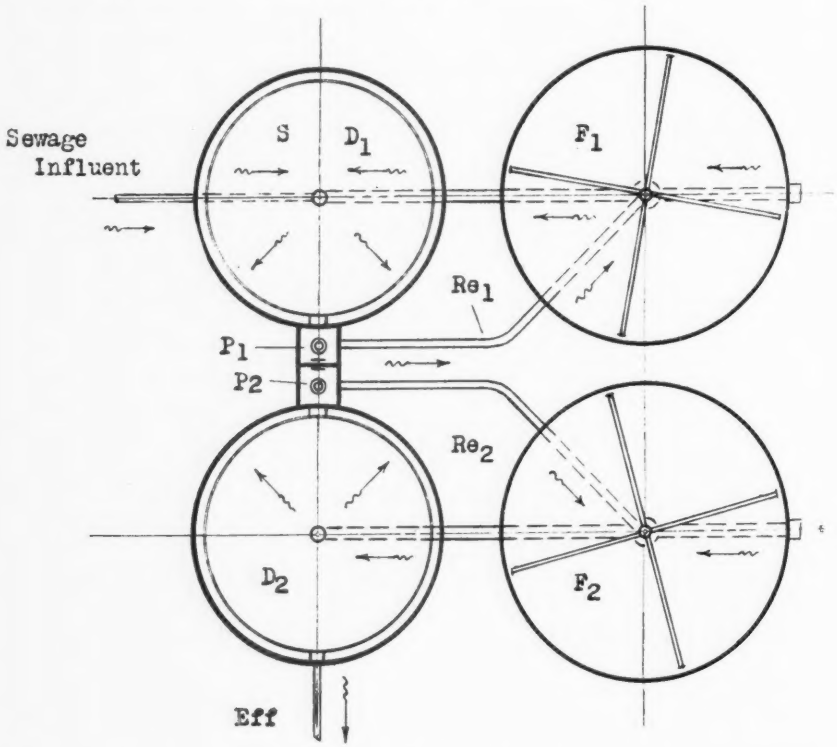

FIG. 8.—Two-stage treatment. Subscripts 1 and 2 refer to the primary and secondary stages, respectively.

Key to Abbreviations

S = Primary settling tank
D = Detention tank
F = Bio-filter bed
P = Recirculation pump
Re = Recirculation system
Eff = Final effluent from plant
Arrows indicate normal direction of flow

studied, the division of filter rock between the primary and secondary stages does not greatly influence the over-all purification. A strict interpretation of the data, however, indicates that it may be desirable to make the primary bio-filter bed greater in area, for equal depths; or else to provide a greater depth in the primary-stage unit, in order to make all the beds of equal area. The coarser rock of the primary bio-filter lends itself well to the latter principle of design.

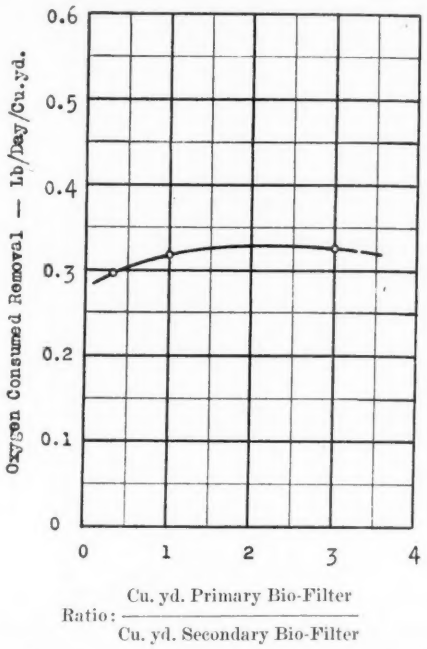

FIG. 9.—Curve showing influence on purification exerted by various relative volumes of filtering material, in stage treatment.

Grading of Filter Medium.—The influence of rock size on purification effected has been studied with two gradings of material, as shown graphically in Fig. 7.

From the results it appears that increased size of rock does not condition the degree of purification so much as the time required to obtain it. For example, from Fig. 7 it may be observed that 78 per cent reduction of B.O.D. is reached in 1 hour with the ½ in. to ¾ in. rock, whereas a time lag of 5 hours occurs before the same removal is effected by the 1½ in. to 2½ in. filter medium.

COLLATERAL QUALITATIVE OBSERVATIONS

Sludge Production and Disposal.—It has been observed that a characteristic sludge is developed within the bio-filter which appears to have oxidizing capacity similar to that of activated sludge, combined,

however, with unusually good settling properties. Qualitative tests, particularly at the Orange County experimental plant, where the question of sludge disposal was studied, showed that the bio-filter sloughings, together with the primary sludge, underwent complete and normal fermentation in a separate sludge digestion tank. (See Fig. 1–*B*.)

The bio-filter sludge is stabilized to an important degree within the system itself. A significant amount of aerobic digestion occurs as the material is successively recirculated through the filter bed, particularly when the sludge is returned to the filter through the recirculation system, as may be done when required.

Detention Tank Operating Characteristics

Determination of the Detention Period.—An inspection of the curves of Fig. 7, which show the progressive purification of the sewage with time, discloses the fact that for the complete treatment of the Salinas sewage the detention tanks should have a holding capacity sufficient for a period of recirculation of from 4 to 6 hours. For stronger sewage or industrial wastes, the detention period should be appropriately increased.

In contrast to complete treatment, and where only an intermediate degree of purification is required, comparable to what may ordinarily be expected of chemical precipitation, a plant should evidently be built to operate on the initial portion of the progressive purification curve. This would involve tankage for between 1 and 2 hours' flow, providing a recirculation period of corresponding duration, wherein a 70 to 80 per cent B.O.D. reduction might be anticipated on the basis of the B.O.D. of the settled sewage influent.

Under such conditions of partial treatment, it is suggested that the detention tank may be designed to include the added function of primary sedimentation of the raw sewage.

Adequacy of Detention Tank Sedimentation.—In view of the repeated turn-over of the detention tank contents, inherent in the practice of recirculation, the adequacy of sedimentation within such a tank has been continually under observation during the Salinas tests. On this point experimental evidence is consistent in demonstrating that the removal of suspended solids is not only satisfactory, but, when stage-treatment is practised, it is more nearly complete than ordinarily attained in the operation of the final settling tanks of the activated-sludge process at Salinas.

Observations at the Salinas research plant have led to the conclusion that with single-stage treatment, a one-hour period of sedimentation, based on the volume of recirculated flow through the detention tank, is satisfactory; while for two-stage working, a minimum of 30 minutes' settling is similarly required, in both the primary and secondary detention tanks.

Functional Aspects of the Recirculation System

Control Over Quality of Effluent Exerted by Recirculation Rate.—From the standpoint of practical plant operation, the Salinas experiments have corroborated the fundamentally important possibility of controlling, within a broad range of filter loadings, the specific purifying capacity of the bio-filter medium, through varying the rate of recirculation to correspond with changes in the volume and/or concentration of the organic wastes undergoing treatment in the plant.

Fig. 6 shows the relationship between bio-filter loading and purification, for a given value of recirculation rate in terms of rate of filtration. The curve shows that, up to a value of 5,000 gallons per day per cubic yard, the purifying capacity per cubic yard of rock varies directly with the rate of sewage application to the filter bed. The extraordinary magnitude of the rates of sewage application employed in these tests is apparent, when compared with the ordinary range of conventional trickling filter loadings of 200 to 300 gal. per day per cu. yd.

It is significant to note also from Fig. 6 the considerable decrease in oxygen consumed removal per cubic yard when the rate of recirculation was reduced, at the 24 m.g.a.d. rate of filtration, to the values of4.0F and 2.5F. This influence on purification exerted by variations in the ratio, Re/F, is further illustrated by the curve of Fig. 10. This diagram is based on the test results set forth in Table I for the 24 m.g.a.d. constant rate of filtration.

From Fig. 10 it appears that for single-stage treatment at rates of recirculation exceeding 5F, the specific purifying capacity of the bio-filter rock cannot be economically augmented through increased recirculation alone. It is anticipated that further tests will disclose the fact that the prolongation of the curve of Fig. 10 will reach a maximum between values of 6.0 and 8.0 for the ratio Re/F. This maximum value may also be a point of contraflexure for the curve, by reason of the impairment of biologic efficiency resulting from excessive rates of passage of the liquid through the bio-filter bed.

Concomitant Effects of Recirculation.—The introduction of the principle of recirculation into the operation of the trickling filter is attended by important possibilities for further improvement in plant characteristics. One is the control of filter flies and the other is the diminution of plant odors.

As regards both these possibilities, full-scale plant operating experience is obviously needed to establish the conclusion that bio-filtration affords practical immunity from plant nuisances. Nevertheless in all experimental plant operation thus far, the author has been impressed with the unusual freedom from *psychoda,* as well as from local filter odors.

It is considered that the immediate dilution of the applied sewage before being distributed over the filter bed tends to minimize odors; while the high rate of recirculation, including specifically high rates of

filtration, prevents the active development of insects, by drowning. In effect, it is not improbable that a bio-filter plant will require very little more plant isolation than is now deemed necessary for activated sludge installations.

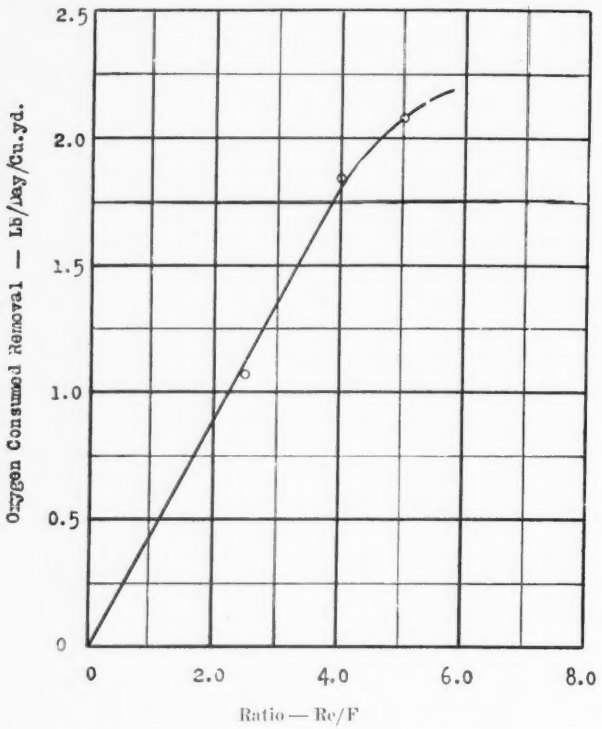

FIG. 10.—Relationship between unit purifying capacity of filtering material and rate of recirculation, single-stage bio-filtration.

Constant Factors

Rate of filtration .... F = 24 m.g.a.d.
Filtering materials
Rock size ..... s = 1½"—2½"
Depth of bed ..... y = 3 feet
Detention period .... D = 2 hours

OXYGEN TENSION AND BACTERIAL NUMBERS *

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In aerobic sewage treatment processes the necessity for an adequate supply of oxygen has been sufficiently recognized. However, the level of oxygen tension to be maintained for optimum reaction has been determined by several considerations such as economy, feasibility and empirical observations, rather than an actual knowledge of the optimum oxygen tension. The optimum oxygen tension for the various aerobic processes will depend in turn on the requirements of the bacteria responsible for the different transformations. In spite of the recent advances made in this direction by the isolation of the aerobic zoogleal organism by Butterfield [2] from activated sludge, it would be hazardous at present to work out the optimum oxygen requirement for the activated sludge process on the basis of the oxygen requirements of these organisms. It seemed desirable, therefore, at present to determine the optimum oxygen requirement of the sewage flora as a whole, by determining the differences in their numbers when subjected to different oxygen tensions but otherwise under identical conditions. We realized that the effect on the numbers is not identical with the effect on their activities or the extent of their oxygen consumption. We further realized that the determination of the numbers of bacteria by plate counts in such a study may not yield a true picture of the shift in types and numbers of bacteria as affected by the different oxygen tensions.

Method

The oxygen from phosphate-buffered distilled water was removed by boiling. The water was then cooled under alkaline pyrogallol traps. To each 4-liter quantity of the water 5 to 10 c.c. of sewage was added. Then a certain amount of air was introduced and shaken with the water. The water, while still under the alkaline pyrogallol traps, was siphoned into 250 c.c. sterile glass-stoppered bottles. These were tightly stoppered immediately and incubated at 20° C. A range of oxygen tensions was thus prepared by introducing different amounts of air. Oxygen gas was also used to obtain oxygen tensions higher than air saturation. At daily intervals for three days bottles were removed to determine the depletion of oxygen and the bacterial numbers. The bacterial numbers were determined by nutrient-broth agar plate counts incubated at 20° C. for 5 days. The results given are the averages of four plates of one of the two dilutions made.

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Div. Water and Sewage Research.

Results

In Table I are given the initial and final dissolved oxygen results for five series of experiments. The initial dissolved oxygen covered a

Table I.—*Initial and Final Oxygen Tensions* (In p.p.m.)

Series	I(1)	F(2)	I(1)	F(2)	I(1)	F(2)	I(1)	F(2)	I(1)	F(2)	I(1)	F(2)	I(1)	F(2)
I.....	.4	0	1.5	.8	3.2	2.1	5.0	4.4	8.1	6.3	—	—	—	—
II.....	.4	.3	1.5	1.5	3.5	2.2	6.1	5.9	8.0	6.9	13.5	12.1	20.0	19.4
III.....	.6	.4	1.5	1.0	3.1	2.3	4.9	4.2	7.7	6.5	15.5	14.6	25.1	25.0
IV.....	.8	.5	1.5	.8	3.1	2.9	5.1	4.6	7.7	6.7	17.8	16.0	31.3	29.6
V.....	.3	.3	1.5	1.3	3.5	3.3	5.4	5.2	7.4	6.8	15.3	14.4	27.5	24.2
Ave.	.5	.3	1.5	1.1	3.3	2.5	5.3	4.8	7.8	6.6	15.5	14.3	26.1	24.5
Depletion		.2		.4		.8		.5		1.2		1.2		1.6

(1) = Initial.
(2) = Final.

range from 0.3 to 31.3 p.p.m. Due to the small amounts of sewage employed, the depletions were kept at a low value. This was considered necessary in order to obtain a D.O. value as constant as possible for the period of incubation. Therefore, there was no overlapping between the different ranges. The average values for the five series give initial D.O. results covering a range from 0.5 to 26.1 p.p.m. The average depletions increased regularly from 0.2 to 1.6 p.p.m. with increasing initial D.O. concentration. With an initial average D.O. concentration of 4.8 p.p.m. the depletion was somewhat lower than with an initial average D.O. concentration of 3.3 p.p.m.

The bacterial numbers for the different D.O. concentrations in the five series are given in Table II. It will be seen that the numbers increased greatly during the first and second days and decreased on the third day. The numbers also increased generally with increasing dissolved oxygen concentrations. This relationship is brought out more clearly in Figure 1, which gives the average values for the five series. The average numbers of bacteria increased regularly with increasing D.O. concentrations, with two exceptions. Within a D.O. range of 6.1 to 4.2 p.p.m. there was a decrease in the numbers for each of the three-day counts over the lower and higher concentration ranges. Similarly at a D.O. range of 31.3 to 19.4 p.p.m. there was a decrease of bacterial numbers over the preceding range. Of the five individual series in the range covering concentrations of 6.1 to 4.2 p.p.m., three were definitely lower and two were either equal to or slightly higher than the corresponding series in the lower range.

Results from an additional series with closer intervals of D.O. concentrations are given in Table III. It will be seen that at a concentration of 4.5 to 5.7 p.p.m. there was a decrease in the numbers of bacteria over lower and higher concentrations of dissolved oxygen. Otherwise the tendency was toward a gradual increase in numbers with in-

creasing D.O. concentrations up to atmospheric saturation, with either the 1 or 2 day counts. It should be noted, however, that the differences are not great.

TABLE II.—*The Effect of D.O. Concentration on the Numbers of Bacteria Developing From Sewage When Inoculated into Phosphate Buffer Water (In Thousands per C.C.)*

D.O. Range			Days			
			0	1	2	3
Initial 0.8	Final 0	1st	8.2	795	450	475
		2nd	5.1	662	717	537
		3rd	63.0	570	440	370
		4th	17.2	567	917	562
		5th	37.0	530	330	210
1.5	.8	1	52.0	710	1130	185
		2	8.5	975	760	950
		3	275.0	770	770	220
		4	32.0	543	550	580
		5	50.0	470	450	210
3.5	2.1	1	44	410	1260	560
		2	11.8	1610	2270	1780
		3	80	850	840	130
		4	15.3	532	567	520
		5	23	310	450	290
6.1	4.2	1	9.3	420	1255	750
		2	15.8	340	—	225
		3	63	840	1090	165
		4	11.6	274	390	547
		5	32	250	160	290
8.1	6.3	1	36.0	720	1925	820
		2	8.8	174	1490	422
		3	96.0	1040	1040	159
		4	8.9	555	1050	630
		5	24.0	540	630	470
17.8	12.1	2	9.3	1160	2420	887
		3	40.0	400	910	625
		4	12.6	1800	2910	2590
		5	19.0	740	720	700
31.3	19.4	2	6.1	550	1460	1710
		3	127.	1050	1340	300
		4	8.4	895	675	900
		5	32.0	350	1300	1590

In Table IV are presented the results obtained with a pure culture of *B. aerogenes* subjected to the different oxygen tensions. The technique was essentially the same as described above except that the menstruum used was Butterfield's [1] dextrose-peptone (5 p.p.m. of each)

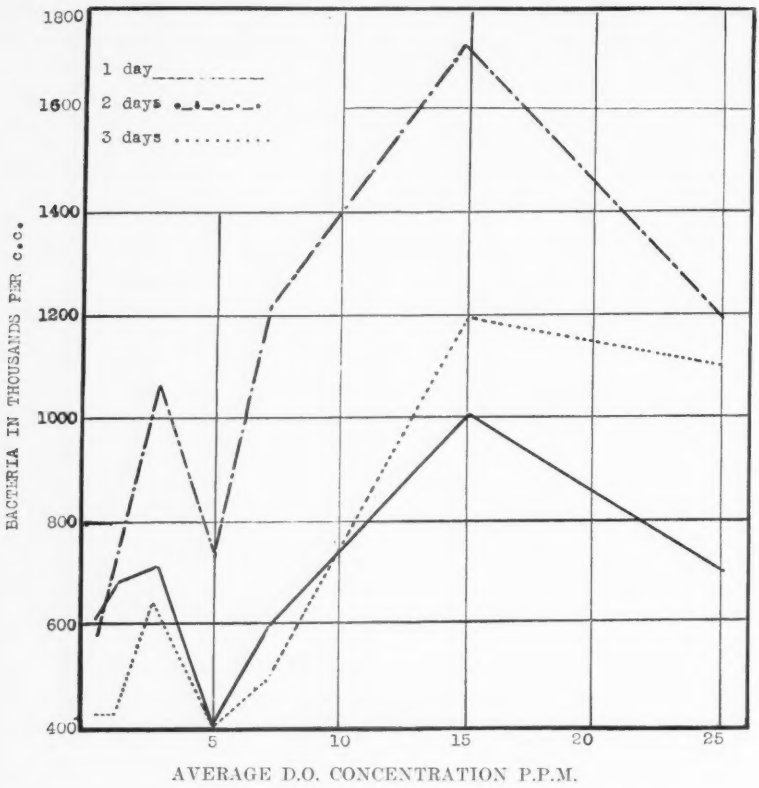

FIG. 1.

TABLE III.—*The Effect of D.O. Concentration on the Numbers of Bacteria Developing From Sewage When Inoculated into Phosphate Buffer Water (In Thousands per C.C.)*

	D.O.		Initial	Days	
	Initial P.P.M.	Final P.P.M.		1	2
1	2.7	2.3	12.0	662	790
2	3.4	2.8	109.0	645	1010
3	4.6	4.5	14.0	490	640
4	5.7	5.5	14.5	517	510
5	6.5	5.7	10.9	895	1160
6	7.7	7.0	23.1	972	1000

phosphate water. The medium was sterilized and cooled under an alkaline pyrogallol trap, inoculated with a 24-hour culture of *B. acrogenes*. The medium was distributed into 250 c.c. sterile glass-stoppered bottles with the necessary precautions to avoid outside contamination.

creasing D.O. concentrations up to atmospheric saturation, with either the 1 or 2 day counts. It should be noted, however, that the differences are not great.

TABLE II.—*The Effect of D.O. Concentration on the Numbers of Bacteria Developing From Sewage When Inoculated into Phosphate Buffer Water (In Thousands per C.C.)*

D.O. Range			Days			
			0	1	2	3
Initial	Final	1st	8.2	795	450	475
0.8	0	2nd	5.1	662	717	537
		3rd	63.0	570	440	370
		4th	17.2	567	917	562
		5th	37.0	530	330	210
		1	52.0	710	1130	185
		2	8.5	975	760	950
1.5	.8	3	275.0	770	770	220
		4	32.0	543	550	580
		5	50.0	470	450	210
		1	44	410	1260	560
3.5	2.1	2	11.8	1610	2270	1780
		3	80	850	840	130
		4	15.3	532	567	520
		5	23	310	450	290
		1	9.3	420	1255	750
		2	15.8	340	—	225
6.1	4.2	3	63	840	1090	165
		4	11.6	274	390	547
		5	32	250	160	290
		1	36.0	720	1925	820
		2	8.8	174	1490	422
8.1	6.3	3	96.0	1040	1040	159
		4	8.9	555	1050	630
		5	24.0	540	630	470
		2	9.3	1160	2420	887
17.8	12.1	3	40.0	400	910	625
		4	12.6	1800	2910	2590
		5	19.0	740	720	700
		2	6.1	550	1460	1710
31.3	19.4	3	127.	1050	1340	300
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In Table IV are presented the results obtained with a pure culture of *B. aerogenes* subjected to the different oxygen tensions. The technique was essentially the same as described above except that the menstruum used was Butterfield's [1] dextrose-peptone (5 p.p.m. of each)

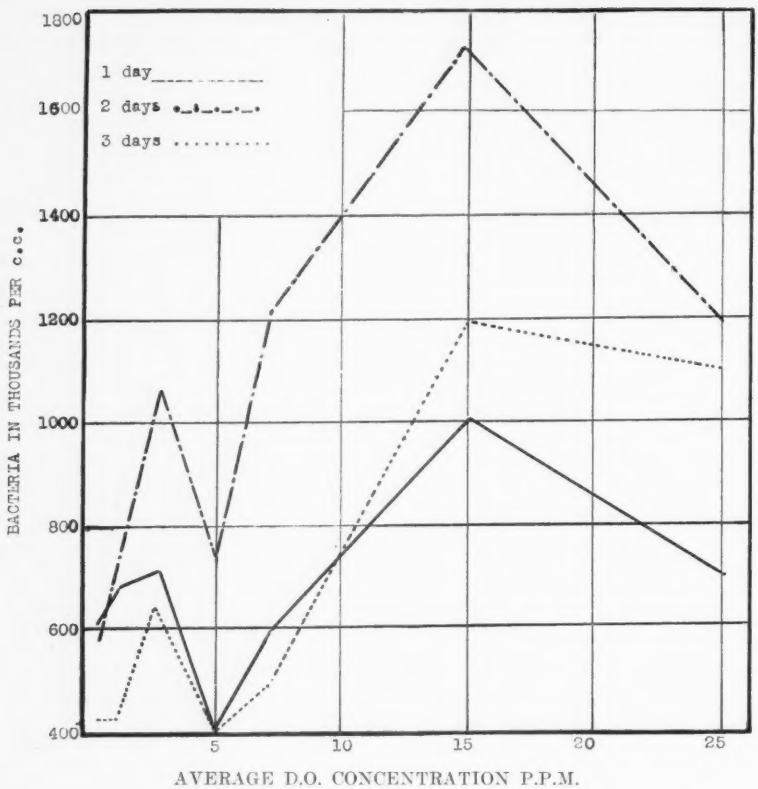

FIG. 1.

TABLE III.—*The Effect of D.O. Concentration on the Numbers of Bacteria Developing From Sewage When Inoculated into Phosphate Buffer Water (In Thousands per C.C.)*

	D.O.		Initial	Days	
	Initial P.P.M.	Final P.P.M.		1	2
1	2.7	2.3	12.0	662	790
2	3.4	2.8	109.0	645	1010
3	4.6	4.5	14.0	490	640
4	5.7	5.5	14.5	517	510
5	6.5	5.7	10.9	895	1160
6	7.7	7.0	23.1	972	1000

phosphate water. The medium was sterilized and cooled under an alkaline pyrogallol trap, inoculated with a 24-hour culture of *B. aerogenes*. The medium was distributed into 250 c.c. sterile glass-stoppered bottles with the necessary precautions to avoid outside contamination.

The D.O. content was adjusted prior to distribution into the individual bottles. Five sets were prepared covering a D.O. range of 0.7 to 7.2 p.p.m. Each day a control bottle without inoculation was tested for sterility; all tests showed negative results. Dissolved oxygen tests and bacterial counts on nutrient agar from inoculated series were also made each day for three days.

TABLE IV.—*Effect of D.O. Concentration on B. aerogenes Inoculated Into Dextrose Peptone Phosphate Buffer Water (In Thousands per C.C.)*

	D.O. (p.p.m.)		Initial	Days		
	Initial	Final		1	2	3
1	.7	0	43	2000	1150	730
2	2.0	0	67	2550	1900	2450
3	3.7	1.9	42	3000	2400	2600
4	5.4	3.3	0.5	660	1720	3440
5	7.2	5.6	61.	4200	2570	2600

The D.O. depletions in three days in the nutrient medium were considerably higher than in the series inoculated with 5 to 10 c.c. of sewage, but there was no serious overlapping of dissolved oxygen. The numbers of *B. aerogenes* increased with increasing D.O. content, with the exception of the series with an initial D.O. content of 5.4 p.p.m. Here the numbers during the first and second days were lower than in the preceding dissolved oxygen concentrations. However, since the initial numbers in this case were considerably lower than in the rest of the series, the retardation might have been caused by the low initial numbers rather than due to a specific effect of the particular D.O. concentration employed. The numbers on the third day had actually exceeded those of the other concentrations of dissolved oxygen. The rate of increase in this instance was much higher than in any other concentration.

DISCUSSION

The results indicate that bacteria capable of growing on agar plates increase with increasing concentration of dissolved oxygen. The lowest numbers were obtained with the lowest D.O. concentration. Since complete absence of oxygen was obtained only in one case and that only after 3 days of incubation, the results were due to a deficiency of oxygen rather than to complete anaerobiosis. With increasing D.O. concentration up to 4.0 to 6.0 p.p.m. the numbers of bacteria increased. At this range however a decrease took place (parallel with the decrease in the depletion of D.O.). Within the range of atmospheric saturation the numbers increased again. The numbers increased further at a D.O. range of 12 to 18 p.p.m. but beyond this range they again decreased.

Two optimum D.O. concentrations are indicated, one at a range 2.0 to 3.5 p.p.m. and the other at a range of 12 to 18 p.p.m. This observation might be attributed to two different types of bacterial flora

which find other optima at these ranges and the dip in the curve might indicate the transitional range.

No consideration has been given to the rates of bacterial increase because the initial numbers sometimes varied. Since the population level is not affected greatly by the initial numbers an undue emphasis would be laid on the influence of initial numbers if the results were expressed on the basis of rates of increase.

Waksman and Carey [3] reported that at a D.O concentration of 3.95 c.c. per liter (5.64 p.p.m.) the bacterial development took place only slowly but at a D.O. concentration of 4.75 c.c. per liter (6.8 p.p.m.) bacterial multiplication was normal. They found corresponding differences in the oxygen consumption. Their work dealt mainly with sea water and the effects produced by such relatively small variations in the D.O. concentrations were much more pronounced than the results reported here. Differences in the type of flora in sea water and sewage might account for the divergence of the results.

We have no results on the rate of consumption of oxygen at the different D.O. tensions. The amount of sewage added and the consequent depletions were so small that it would be difficult to draw conclusions from the observed differences in the depletions. With D.O. concentrations below atmospheric saturation, the tendency would be to absorb oxygen slowly from the air through the glass-stoppered bottles, thereby decreasing the observed depletions in D.O. On the other hand with D.O. values higher than saturation at atmospheric pressure the tendency would be for the oxygen to escape into the air, causing greater depletions.

The rate of oxidation may or may not be affected by the variations in the D.O. concentration, depending on whether the observed increases in the numbers of bacteria are due to organisms responsible for oxidation or to a mere selection of organisms capable of growing on agar plates under aerobic conditions. It is interesting to note, however, that the pure culture of *B. aerogenes* showed similar increases with increasing D.O. concentrations.

If the rate of oxygen consumption is affected in a similar way as bacterial numbers serious objections might be raised as to the validity of the B.O.D. method. In this determination the oxygen consumption is assumed to be unaffected by the different D.O. concentrations above a certain minimum. Our results, from the standpoint of bacterial numbers, do not indicate the presence of such a minimum but a gradual effect with increasing concentrations. Furthermore, there appears to be a retardation of bacterial development at a D.O. concentration between 4.0 and 6.0 p.p.m. Since B.O.D. determinations are made covering a range between 8.0 to 1.0 p.p.m. these differences in bacterial development might be reflected in the oxygen consumption rates.

In regard to the activated sludge process it is difficult to make specific recommendation in respect to the optimum D.O. concentration with the available data. It would seem, however, that an increase in the rate

of oxidation might be obtained if higher D.O. concentrations could be maintained.

But since the successful operation of an activated sludge plant involves other factors in addition to the rate of oxidation, it might be well to withhold judgment pending further investigations dealing with the effect of oxygen tension on the rate of oxidation, purification and the character of the sludge.

Summary

Using sewage as an inoculum into phosphate-buffer water and maintaining definite dissolved oxygen concentration in closed systems an increase of bacterial numbers (on agar plates) has been observed with increasing D.O. concentration, with an incubation period of 1 to 3 days. The D.O. concentrations covered a range from 0 to 31.3 p.p.m. At the approximate range of 4 to 6 p.p.m. the increase in the rate of multiplication was not as high as in the lower concentration. Attention is called to the relation between the rate of oxygen consumption and the B.O.D. determination.

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2. C. T. Butterfield, "Studies of Sewage Purification. II. A Zooglea Forming Bacterium Isolated from Activated Sludge," *Pub. Health Rept.*, **50**, 671 (1935).
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CHEMICAL COAGULATION OF SEWAGE *

III. Effect of Pre-settling

By Willem Rudolfs and H. W. Gehm

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Pre-settling of sewage prior to chemical treatment is practiced at some places with apparently beneficial results. Enslow [1] states that the results obtained at Palo Alto, Calif., and at Birmingham, Ala., have demonstrated the value of the method. The report of the A. P. H. A. committee on chemical treatment [2] states that the value of pre-settling prior to coagulation remains to be proven. Tests made by the Sanitary District of Chicago did not show any significant difference in B.O.D. reductions due to pre-settling.

In a discussion of the value of pre-settling it should be kept in mind that in chemical coagulation the chief interest lies in the finely divided suspended, pseudo-colloidal and colloidal particles which will not settle within a reasonable time, as well as in the soluble fraction of the sewage, rather than in the removal of coarser material. The non-settleable fraction of suspended material that imparts turbidity to the liquid is by far the most important, although it may account only for 30 to 45 per cent of the total suspended solids. In a subsequent paper it will be shown what percentages of the chemical demand are exerted by the different fractions of the solids of different types of sewages.

The present paper deals with the effect of settleable solids concentration, when varied in a given sewage, on the removals obtained in different types of chemical treatment. Determinations of turbidity and suspended solids of the supernatant liquid have been used as the index of clarification, because the correlation between turbidity and suspended solids in chemical effluents has been shown [3] to be sufficiently close to warrant the use of turbidity measurements in this type of studies. The data given in this paper are in agreement with the former results. B.O.D. reductions are not necessarily in close agreement with turbidity and suspended removals. The effect of coagulation on rates of B.O.D. reduction will be shown elsewhere. Depending upon the type and condition of the sewage clarification, as represented by turbidity and suspended solids removals, turbidity removal may or may not be accompanied by proportional B.O.D. reduction. The statements made by Enslow and the results obtained by the Sanitary District are therefore not necessarily in conflict, but indicate that generalization can not always be made from one particular sewage, especially when the sewage contains industrial wastes. The conclusions drawn in the present paper are based upon experiments with domestic sewages and are illustrated by typical results obtained.

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Procedure

The experiments to determine the effect of different suspended solids concentrations were conducted on sewages collected in 5-gallon cans. Three cans with the sewage obtained from the same place and at the same time constituted a series. The sewage in one can was used as collected, while the sewage in the two others was allowed to settle for a period of 2 hours. At the end of this period about half of the supernatant was siphoned off and used for lower solids concentration runs. The contents remaining in the two cans were mixed and used for high solids concentration, allowing three different suspended solids concentrations from the same sewage. Aliquots of 1.5 liter were adjusted with sulphuric acid or calcium hydroxide to different pH values and iron salt solution was added with violent mixing. The aliquots were then stirred at 16 r.p.m. for a 30-minute period and allowed to settle for one hour. Turbidity and suspended solids were determined on the supernatant of the treated sewage.

Results

The results presented were obtained with very fresh sewage samples from Highland Park, N. J., and stale sewage samples from Plainfield, N. J. Using ferric chloride alone as coagulant without pH adjustment the variation in settleable solids present in the sewage does not affect the clarification of sewage. Examples of four sewages with varying iron demands and different total suspended solids concentrations, as given in Table I, show that the response of settled sewage was

Table I.—*Effect of Varying Amounts of Ferric Chloride on Clarification (Results as P.P.M. Turbidity Remaining)*

Sewage	P.P.M. Total Suspended Solids	P.P.M. Fe as $FeCl_3$										Means
		5	10	15	20	25	30	35	40	45	50	
1	112	57	33	26	5	—	—	—	—	—	—	30
	352	62	35	24	5	—	—	—	—	—	—	32
	740	61	30	22	5	—	—	—	—	—	—	30
2	107	—	—	—	65	35	15	5	—	—	—	30
	286	—	—	—	60	39	19	5	—	—	—	31
	441	—	—	—	68	41	15	5	—	—	—	32
3	148	—	—	—	—	—	73	39	25	5	—	35
	327	—	—	—	—	—	70	39	22	5	—	34
	653	—	—	—	—	—	68	36	27	5	—	34
4	130	—	—	—	—	—	81	52	28	10	5	35
	297	—	—	—	—	—	77	57	30	7	5	35
	465	—	—	—	—	—	79	47	25	10	5	33

not different from unsettled sewage, or when the settleable solids concentration was increased. The quantities of iron required to produce complete clarification, with the standardized method of application, mixing, stirring and settling, was the same for each group of sewages. If the percentage of the total suspended solids removal is taken, the sewages with the greatest amounts of initial total suspended solids naturally showed the greatest removal. Since the coarser solids settled without chemicals the calculation of percentage removal on the basis of the initial total suspended solids has no value in this respect. It is also interesting to note that the increase in total suspended solids had no effect upon partial clarification of the sewage. With any given quantity of iron salt added the turbidity remaining was practically constant.

The question might be raised (1) whether the increased quantities of coarse suspended solids are an aid in floc formation, so that the same effluent may be produced with a shorter time of coagulation, or (2) whether the time of settling required to produce equal results is not shorter with larger amounts of suspended solids. When floc formation observations are made it appears that the floc is larger when more settleable solids are present. When the coarser particles are removed the formation of the floc appears to be slower, or rather the size of the floc particles formed is smaller. These smaller floc particles give the liquor an opaque appearance. These smaller floc particles usually settle as cleanly as those where coarser suspended solids are present. In order to determine the actual clarification of the different sewages with varying quantities of suspended solids present during different times of coagulation, samples of sewage were stirred at 16 r.p.m. and the turbidity determined at intervals. The results of a typical set of results at the given speed of stirring are shown in Figure 1. It is obvious that for all practical purposes the degree of clarification at different periods of time was similar. The visual observation that floc formation was apparently more rapid with increased suspended solids appears to be due to the fact that the liquid seen through the larger particles is, by contrast, clearer in the sewage than the liquid between the spaces of the finer floc particles.

If the settleable solids should form a nucleus for the fine coagulated floc particles, or on account of their weight should carry down the finer particles, it could be assumed that better settling would result, or in other words that the time required for equal settling with the same quantities of coagulant would vary with the amount of initial suspended solids present. To determine whether this assumption was correct, samples of sewage were treated with equal quantities of iron salts, stirred and coagulated for different periods of time, and two-thirds of the supernatant was removed for suspended solids determinations. A series of results, employing the same sewage with different suspended solids concentrations, but rather difficult to coagulate, and another sewage, easier to coagulate with about the same amount of iron salt, are shown in Table II. With about the same quantities of ferric chloride,

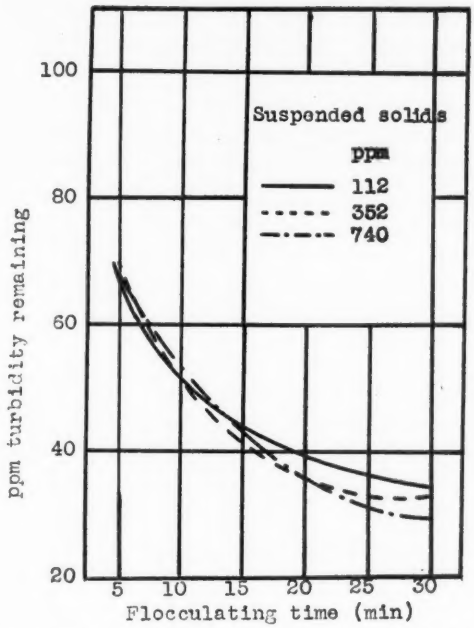

FIG. 1.—Effect of coagulation time on turbidity removal, using different sewages.

TABLE II.—*Settling of Partially and Completely Coagulated Sewage*

Settling Time, Min.	*Suspended Solids Remaining in P.P.M.*			P.P.M. Fe as $FeCl_3$
	Partially Clarified			
0	147	276	468	25
15	116	128	126	
30	104	108	120	
60	102	108	106	
120	110	102	102	
	Completely Clarified			
0	144	224	356	27.5
15	36	17	14	
30	27	12	13	
60	4	3	3	

clarification was practically complete in one series, whereas in the other only partial clarification was accomplished. It appears that the rates of settling of completely clarified sewage with higher solids concentrations was somewhat greater during the first 30 minutes of sedimentation, but was the same for all concentrations after 60 minutes settling. On the basis of the sewage without additional suspended solids added, the difference after 15 minutes settling was 12 per cent for the medium and 15 per cent for the strongest sewage.

For partially clarified sewage no practical differences were found after 60 minutes settling, although there was a tendency toward producing a slightly more turbid effluent during shorter sedimentation with higher solids concentrations. On the basis of one or two hours settling the rates of settling were constant for all solids concentrations, whether completely or partially clarified with ferric chloride alone.

The results thus far reported deal with the addition of iron salts without reaction control. It has been shown in a previous paper [3] that maximum coagulation can be obtained in two pH ranges, one on the acid and one on the alkaline side. It is possible that an increase of suspended solids at the points of maximum pH ranges for coagulation might result in increased clarification.

Increased suspended solids concentrations appeared to have no effect upon clarification when the pH values were lowered into the acid range, where more complete coagulation is accomplished. As an example, the averages of three sets of experiments, using a coagulant dose of 8.5 p.p.m. iron as ferric chloride and varying initial suspended solids concentrations, are plotted in Figure 2. The suspended solids remain-

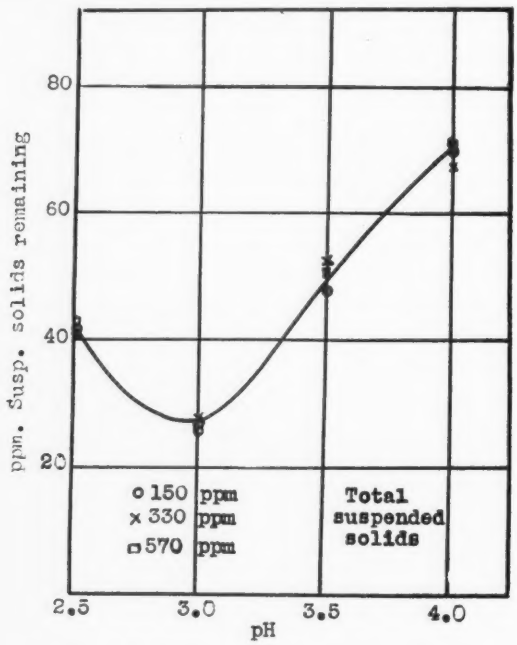

FIG. 2.—Effect of suspended solids concentration on clarification in the acid range of coagulation.

ing in the effluent varied with the pH value but not with the solids concentration.

Using the same iron dosage (8.5 p.p.m.) and adjusting the pH values with lime to the alkaline range of optimum coagulation the presence of settleable solids appears to play a part in the clarification process. The average results of seven series of experiments are shown in Figure 3. It will be observed that in the alkaline range of optimum coagula-

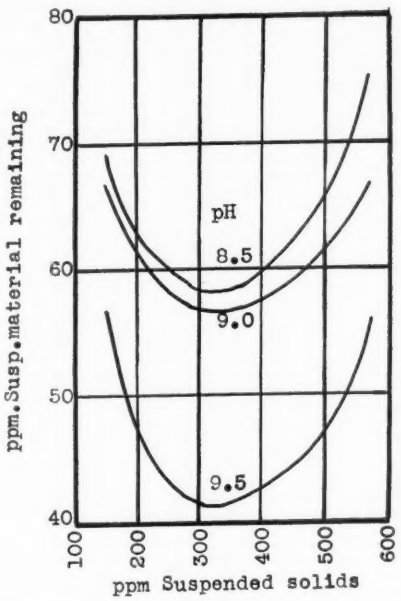

FIG. 3.—Effect of suspended solids concentration on clarification in the optimum alkaline range of coagulation.

tion, results were best with average concentrations of 300 to 350 p.p.m. suspended solids. Lower and higher concentrations produced effluents with higher turbidities.

Previous experiments showed that without pH adjustment the effect of varying suspended solids concentrations was nil. The nearer the optimum point of coagulation was approached (about pH 9.5) the greater was the effect of solids concentration. With the optimum solids concentration (330 p.p.m.) the average remaining turbidity was at pH 9.0 only 9 per cent less than at pH 8.5, whereas at pH 9.5 the difference had increased to 25 per cent. This difference was fairly constant over the range of 150 to 600 p.p.m. original suspended solids. Although the difference is not extensive, it appears to be positive; the results demonstrate the beneficial effect of the settleable solids concentration when lime is used in conjunction with an iron salt coagulant. It demonstrates also that with a weak sewage the effect will be more beneficial than with a strong sewage.

Discussion

Pre-settling of sewage in the process of sewage coagulation does not appear of importance for clarification with an average quantity of suspended solids present, in respect to the coagulant demand. However, when a weak sewage is treated and the pH values of the sewage are adjusted to the alkaline range of optimum coagulation, the presence of settleable solids somewhat improves clarification. Only when sewages containing larger quantities of settleable solids are treated, and the reaction is properly adjusted, would pre-settling have a beneficial effect. Since pre-settling has no effect when iron salts alone are added, nor in the acid range of coagulation, the beneficial or detrimental effects to be expected depend upon the method of coagulation and the original quantities of suspended solids present. The practice of pre-settling in connection with sludge concentration, where bulky chemical sludge is returned to the influent to settle with the fresh solids to form a denser sludge in the settling tank, would not be detrimental to the succeeding coagulation process. It is conceivable that the solids concentration may be so low in a very weak sewage that necessary nuclei for floc formation are absent and an increase in solids concentration might be beneficial. Addition of settleable solids undoubtedly results in an increase in finely divided solids, as measured by turbidity. This increase may become so great that the beneficial effect is overcome, resulting again in greater remaining turbidity. Nuclei are necessary, but perform only a certain amount of service and this service varies with the quantity of coagulant. It is clear, therefore, that when more coagulant is used, with greater solids concentration, the removal of finely divided suspended solids would be greater at a given pH value. This means that for a given turbidity removal a definite quantity of coagulant and a definite amount of suspended solids (nuclei) must be present. These quantities vary from place to place (strength of sewage) and are also dependent upon the character of the sewage. As a rule, increased solids concentration might be beneficial when the sewage is low in colloidal and finely divided suspended solids. When sufficient fine suspended solids are present the larger particles are of little importance in the coagulation process.

The effect of solids concentration and the return of different types of sludge on the rates of settling and compacting will be discussed in a subsequent paper.

Summary

Three types of chemical treatment were applied to raw sewages, pre-settled sewages and sewages in which the settleable solids concentration had been increased. No effect of variation in solids concentrations upon the clarification of sewage could be observed when ferric chloride alone was used as coagulant, or when the acid-ferric chloride process was practiced. Pre-settling of an average strong sewage was

somewhat detrimental to clarification when the iron-lime process was employed, but was beneficial when the sewage contained large quantities of settleable solids. Pre-settling in connection with return of chemical sludge to the influent, to produce a denser sludge, would not be detrimental to the succeeding coagulation process. The initial settling rates of completely clarified sewage were somewhat less for pre-settled sewage, while no effect of solids concentration was noticed with partially clarified sewage.

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THE "LOG-DIFFERENCE" METHOD OF ESTIMATING THE CONSTANTS OF THE FIRST-STAGE BIO-CHEMICAL OXYGEN DEMAND CURVE

By Gordon M. Fair

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Formulation of the first-stage biochemical oxygen demand of polluted water as a unimolecular reaction yields the following equation:

$$Y_t = L(1 - 10^{-kt}). \tag{1}$$

Here

Y_t = B.O.D. exerted in time t

L = Ultimate B.O.D. of first stage

k = reaction velocity constant.

L and k are the constants of the B.O.D. curve.

The statistical treatment of reaction velocity data of this type has been thoroughly studied by Reed and Theriault [1, 2] who have developed, as a result, a "least-squares" method of evaluating the constants L and k which is mathematically consistent and straightforward. Unfortunately this method is quite laborious and involves the use of a trial value of k which must closely approximate the magnitude of k ultimately derived, if repetition of a long series of computations is to be avoided. For this latter reason alone it seems worth while to find a simple way of establishing a closely approximate value of k and from it, if desired, a closely approximate value of L. Frequently, too, these approximate values may be sufficient for the purposes of the investigation and a simple and rapid procedure may encourage the wider determination of the magnitudes (even though only approximate) of these important constants.

The author submits, therefore, what he believes to be a new, rapid and simple procedure for approximating the values of k and L by what may be called the "log-difference" method. The approach was suggested in part by Guggenheimer,[3] and requires that the B.O.D. be observed at equal intervals of time.

To find k.—If we let i equal a uniform interval of time, then:

$$Y_t = L[1 - 10^{-kt}] \tag{2}$$

$$Y_{(t+i)} = L[1 - 10^{-k(t+i)}]. \tag{3}$$

Subtracting the upper from the lower equation and letting $Y_{(t+i)} - Y_t$ equal d, we have

$$d = L \cdot 10^{-kt} - L \cdot 10^{-k(t+i)} = L(1 - 10^{-ki})10^{-kt} \tag{4}$$

$$\log d = [\log L + \log (1 - 10^{-ki})] - kt. \tag{5}$$

Here $[\log L + \log (1 - 10^{-ki})]$ is constant, since i is uniform. Hence

$$\log d = \text{constant} - kt = c - kt. \tag{6}$$

This is a linear equation for which the value of k may be found by "least squares" procedure, employing the n equally spaced "observation equations." According to this procedure, the sum of the squares of the residuals, $R = c - kt - \log d$, must be a minimum, or ΣR^2 equals a minimum. (The symbol Σ is employed to denote "the sum of".) This condition is fulfilled when the partial derivatives of ΣR^2 with respect to c and k are set equal to zero. The two "normal equations" thus obtained may then be solved for k and c. The value for c, however, will not be noted in this paper. The mathematical development follows.

$$\Sigma R^2 = \Sigma(c - kt - \log d)^2 \tag{7}$$

$$\frac{\partial \Sigma R^2}{\partial c} = 2\Sigma(c - kt - \log d) = 0 \tag{8}$$

$$\Sigma(c - kt - \log d) = nc - k\Sigma t - \Sigma \log d = 0 \tag{9}$$

$$\frac{\partial \Sigma R^2}{\partial k} = 2\Sigma(c - kt - \log d)(-t) = 0 \tag{10}$$

$$\Sigma(-ct + kt^2 + t \log d) = -c\Sigma t + k\Sigma t^2 + \Sigma t \log d = 0. \tag{11}$$

Eliminating c from equations (9) and (11) by multiplying them by Σt and n respectively and summing:

$$nk\Sigma t^2 + n\Sigma t \log d - k(\Sigma t)^2 - \Sigma t \Sigma \log d = 0$$

$$k[n\Sigma t^2 - (\Sigma t)^2] + n\Sigma t \log d - \Sigma t \Sigma \log d = 0$$

$$k = \frac{\Sigma t \Sigma \log d - n\Sigma t \log d}{n\Sigma t^2 - (\Sigma t)^2}. \tag{12}$$

Since the n values of t are equally spaced, we may determine:

$$\Sigma t = (1 + 2 + 3 \text{ etc.}) = \frac{n(n+1)}{2}$$

$$(\Sigma t)^2 = (1 + 2 + 3 \text{ etc.})^2 = \frac{n^2(n+1)^2}{4}$$

$$\Sigma t^2 = (1 + 4 + 9 \text{ etc.}) = \frac{n(n+1)(2n+1)}{6}.$$

Substituting these quantities in equation (12) and simplifying, we obtain the following equation for the estimation of k:

$$k = \frac{6}{n(n^2-1)}[(n+1)\Sigma \log d - 2\Sigma t \log d]. \tag{A}$$

The necessary computations, as exemplified later, merely involve, therefore, a summing of $\log d$ and of $t \log d$.

It should be realized that equation (A) results from the initial assumption that the pairs of equations (2) and (3) are balanced for fixed values of k and L. This is only approximately correct. To determine the value of L, therefore, we shall not employ these assumptions again, but proceed as follows.

To find L.—Returning to equation (1), the determined value of k permits setting up n observations equations from which the best value of L may be ascertained by the "least squares" method. In accordance with the preceding development of this procedure:

$$R = L(1 - 10^{-kt}) - Y_t$$

$$\Sigma R^2 = \Sigma[L(1 - 10^{-kt}) - Y_t]^2 \tag{13}$$

$$\frac{\partial \Sigma R^2}{\partial L} = 2\Sigma[L(1 - 10^{-kt}) - Y_t](1 - 10^{-kt}) = 0 \tag{14}$$

$$L\Sigma(1 - 10^{-kt})^2 - \Sigma(1 - 10^{-kt})Y_t = 0 \tag{15}$$

$$L = \frac{\Sigma(1 - 10^{-kt})Y_t}{\Sigma(1 - 10^{-kt})^2}. \tag{16}$$

$\Sigma(1 - 10^{-kt})^2 = n - 2\Sigma 10^{-kt} + \Sigma 10^{-2kt}$, and for equal spacing of t:

$$\Sigma(1 - 10^{-kt})^2 = n - 2 \times 10^{-k}\frac{10^{-nk} - 1}{10^{-k} - 1} + 10^{-2k}\frac{10^{-2nk} - 1}{10^{-2k} - 1}$$

or

$$\Sigma(1 - 10^{-kt})^2 = n - 2 \times 10^{-k}\frac{1 - 10^{-nk}}{1 - 10^{-k}} + 10^{-2k}\frac{1 - 10^{-2nk}}{1 - 10^{-2k}}.$$

Substituting this value in equation (16):

$$L = \frac{\Sigma(1 - 10^{-kt})Y_t}{n - 2 \times 10^{-k}\dfrac{1 - 10^{-nk}}{1 - 10^{-k}} + 10^{-2k}\dfrac{1 - 10^{-2nk}}{1 - 10^{-2k}}}. \tag{B}$$

Again the necessary calculations are very simple. Determination of the n values of 10^{-kt} serves a dual purpose, since these values are needed in order to compare the calculated values of Y_t with the observed values.

Example.—The necessary computations may be illustrated at the hand of a typical B.O.D. study, such as Theriault's * study of Ohio River water. Theriault observed the values of Y_t in the times t listed in the table. Only the results for the first 10 days are included to avoid the influence of nitrification. Three values had to be interpolated graphically to secure equal time intervals. These values are starred.

All calculations are simple and straightforward. They can be made by use of a four-place log table and do not require employing a calculating machine and 6-place auxiliary tables of $(1 - 10^{-kt})$ and $t \times 10^{-kt}$, as does Reed and Theriault's [1, 2] "least-squares" method. The approximated values of L and k are $L = 2.875$ and $k = 0.0992$. It will be noted that

* Reference (2), p. 122, Series No. 7, 20° C.

TABLE I.—*Calculation of k and L by the "Log-Difference" Method*

t	Y_t	d	log d	t log d	kt	10^{-kt}	$1-10^{-kt}$	$Y_t(1-10^{-kt})$	Y_t'
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	0.705	0.705	0.8482–1	0.8482–1	0.09915	0.7959	0.2041	0.144	0.59
2	1.06	0.355	0.5502–1	1.1004–2	0.19830	0.6334	0.3666	0.389	1.05
3	1.54	0.48	0.6812–1	2.0436–3	0.29745	0.5041	0.4959	0.764	1.43
4	1.70	0.16	0.2041–1	0.8164–4	0.39660	0.4012	0.5988	1.018	1.72
5	1.88	0.18	0.2553–1	1.2765–5	0.49575	0.3193	0.6807	1.280	1.96
6*	2.11*	0.23	0.3617–1	2.1702–6	0.59490	0.2542	0.7458	1.574	2.14
7	2.31	0.20	0.3010–1	2.1070–7	0.69405	0.2023	0.7977	1.843	2.29
8*	2.42*	0.11	0.0414–1	0.3312–8	0.79320	0.1610	0.8390	2.030	2.41
9*	2.50*	0.08	0.9031–2	8.1279–18	0.89235	0.1281	0.8719	2.180	2.51
10	2.57	0.07	0.8451–2	8.4510–20	0.99150	0.1020	0.8980	2.308	2.58
Sums			4.9913–12	27.2724–74				13.530	
			−7.0087	−46.7276					

$$(A)\quad k = \frac{6}{n(n^2-1)}[(n+1)\Sigma \log d - 2\Sigma t \log d]$$

$$= \frac{6}{10 \times 99}[11 \times (-7.0087) - 2 \times (-46.7276)] = 0.09915.$$

$$(B)\quad L = \frac{\Sigma(1-10^{-kt})Y_t}{n - 2 \times 10^{-k}\dfrac{1-10^{-nk}}{1-10^{-k}} + 10^{-2k}\dfrac{1-10^{-2nk}}{1-10^{-2k}}}$$

$$= \frac{13.530}{10 - 2 \times 0.7959\dfrac{0.8980}{0.2041} + 0.6334\dfrac{1-(0.1020)^2}{0.3666}} = 2.875.$$

(1) Time in days.
(2) B.O.D. observed in stated time.
(3) B.O.D. increment in each time interval = difference in successive values of column (2).
(4) Log of column (3).
(5) Column (1) × column (4).
(6) Column (1) × k.
(7) Antilog of [− column (6)] = antilog of {[1 − column (6)] − 1}.
(8) 1 − column (7).
(9) Column (2) × column (8).
(10) L × column (8) = calculated B.O.D.

the agreement between observed and calculated values of the B.O.D. is good.

Using a trial value of $k = 0.100$ in the Reed and Theriault method for computing L and k, the calculated values are $L = 2.833$ and $k = 0.1030$. The "log-difference" method, therefore, yields estimates of L and k in the case under consideration that lie respectively within 1.5 and 3.7 per cent of the values obtained by the far more laborious "least-squares" method. As previously stated, a satisfactory solution of the problem by the "least-squares" method, furthermore, requires a close selection of a trial value of k. This selection may be aided by finding a trial value of k by the "log-difference" method, a very rapid and simple procedure which involves only the first five columns of the table.

It may be of interest to compare the values of Y_t as fitted by the "log-difference" and "least-squares" method. The values are listed in Table II.

TABLE II.—*Comparison of Observed and Calculated B.O.D. Values*

t	1	2	3	4	5	6*	7	8*	9*	10
Observed.....	0.705	1.06	1.54	1.70	1.88	2.11*	2.31	2.42*	2.50*	2.57
Least-squares..	0.598	1.07	1.44	1.74	1.97	2.16	2.29	2.41	2.50	2.57
Log-difference..	0.587	1.05	1.43	1.72	1.96	2.14	2.29	2.41	2.51	2.58

It will be noted that the fit is almost as good for the "log-difference" method as it is for the "least-squares" method. The author is inclined to believe, in fact, that biologically activated reactions such as the B.O.D. test do not warrant refinement of calculation that entails a great deal of labor.

Parenthetically, it should be pointed out, in connection with the "least-squares" method, that the values of $\Sigma(1 - 10^{-kt})^2$, $\Sigma(t \cdot 10^{-kt})^2$ and $\Sigma(1 - 10^{-kt})t \cdot 10^{-kt}$, which are needed and which involve the greatest amount of computation, can also be obtained directly* for equally spaced time intervals.

CONCLUSION

The "log-difference" method for estimating the reaction velocity constant, k, of the first-stage biochemical oxygen demand curve may be employed (*a*) to find an approximate value for this constant and, based upon it, also an approximate value for the ultimate first-stage demand, L; (*b*) to find a trial value of k to be employed in finding k and L by the "least-squares" method.

The "log-difference" method is limited in application to observations made at equal time intervals. While it is mathematically feasible to devise means for including observations made at varying time intervals, the method then becomes more laborious and hence less useful; graphical interpolation of missing values is indicated in such cases. So far as the author knows, the "log-difference" and "least-squares" methods are as yet the only means for finding k and L in which it is unnecessary to make any assumptions concerning the magnitude of L.

In closing, the author wishes to acknowledge the coöperation of Messrs. H. A. Thomas and R. B. Thompson, Assistants in Sanitary Engineering in the Harvard Graduate School of Engineering.

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* $$\Sigma(1 - 10^{-kt})^2 = n - 2 \times 10^{-k}\frac{1 - 10^{-nk}}{1 - 10^{-k}} + 10^{-2k}\frac{1 - 10^{-2nk}}{1 - 10^{-2k}}$$

$$\Sigma(t \cdot 10^{-kt})^2 = \frac{10^{-2k}}{1 - 10^{-2k}}\left\{\frac{1}{1 - 10^{-2k}} - \frac{(2n - 1)10^{-2nk}}{1 - 10^{-2k}} + 2\times 10^{-2k}\frac{1 - 10^{2(n-1)k}}{(1 - 10^{2k})^2} - n^2 \cdot 10^{-2nk}\right\}$$

$$\Sigma(1 - 10^{-kt})t \cdot 10^{-kt} = \frac{10^{-k}}{1 - 10^{-k}}\left\{\frac{10^{-k}}{1 + 10^{-k}}\left[n \cdot 10^{-2nk} - \frac{1 - 10^{-2nk}}{1 - 10^{-2k}}\right] + \frac{1 - 10^{-nk}}{1 - 10^{-k}} n \cdot 10^{-nk}\right\}.$$

INFLUENCE OF SUBSTRATE ON BIOCHEMICAL OXYGEN DEMAND *

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During recent years a great deal of experimentation and discussion has been carried on with a view of producing a "standard" dilution water. Various dilution waters have been proposed, some largely on an empirical basis and others based upon the mineral content of the "average" American river water. In all these studies the comparative merits of the various dilution waters were determined by comparing the magnitude of the five-day B.O.D. obtained on sewages and sewage effluents. Natural waters, which have been stored for a period of time in order to reduce the biochemical oxygen demand, have also been tried and evaluated in the same manner. One general conclusion reached by all of these investigations is that the dilution water or substrate does have a significant effect upon the five-day biochemical oxygen demand value.

Butterfield, Purdy and Theriault [1] state that the rate of biochemical oxidation is a function of the rate of growth and reproduction of the viable organisms present. If this is true, the maximum B.O.D. of a waste can be obtained only when sufficient cell-building elements, such as nitrogen, phosphorus and potash, etc. are present in the substrate; the organic food supply of this sewage or waste is then the major limiting factor to bacterial reproduction. We have found no experimental work reported in the literature up to the present time to show the relative quantities of these cell building constituents necessary for the five-day B.O.D. Butterfield [11] concludes from certain experiments that 2,500 parts per million of di-potassium hydrogen phosphate is more conducive to bacterial growth than successively lower quantities, *i.e.*, 250, 50 and 25. He made two assumptions to explain this result, one that the phosphate contained as impurities certain minerals necessary for bacterial growth, and the other, that the high salt concentration might stimulate growth. His results show a better growth, nevertheless, in the solution containing 25 p.p.m. phosphate than in the dilute media containing 250, but not quite so good as that obtained in 2,500 p.p.m. phosphate. He also made limiting experiments on the nitrogen requirements for satisfactory growth, using urea, ammonium sulphate, sodium nitrate and peptone.

In our present study we have tried, not so much to develop a synthetic dilution water, as to show experimentally the effect and the utilization of the constituents of the substrate.

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General Procedure

A glucose solution was selected for this work because of its ease of reproduction, its purity and the simplicity with which quantitative determinations may be made upon it. Paper mill wastes were also used because they are notably deficient in most of the minerals involved in this study.

The seeding throughout was accomplished by growing sewage bacteria on plain agar streak-plates incubated at 20°C. The colonies were washed off with 0.9 per cent solution of sodium chloride, broken up by shaking in a bead flask, filtered through cotton and the resulting suspension used for seeding. Seeding in all cases was uniform within each series but between series the seeding varied from 7,000 per ml. to 84,000 per ml. Several attempts were made to obtain a mixed inoculation of bacteria and protozoa in the seeding process. The protozoa cultures were grown in an aerated mixture of sugar and malt house waste. *Colpidium* and *Lionotus* were the chief varieties used in the inoculum but these apparently did not multiply in the diluted B.O.D mixtures, for they could not be found after three days. In those samples inoculated with the mixture of microscopic life, the B.O.D. did not differ essentially from that obtained when inoculation was made only with mixed cultures of sewage bacteria grown on the surface of agar plates.

Laboratory Procedures

In all of this work the dissolved oxygen was determined by the Winkler Method as modified by Theriault and McNamee.[2]

The dilution water-base was aged distilled water containing 300 p.p.m. sodium bicarbonate. The distilled water contained less than .08 p.p.m. N as free ammonia. The seeding was accomplished by adding a sufficient quantity of the bacterial suspension to the five-gallon bottles of bicarbonate dilution water. Bacterial numbers present in B.O.D. mixtures at start and during succeeding days were determined by counting the number of colonies developing on agar plates, as recommended by Standards Methods of American Public Health Association 1933, using appropriate dilutions.

The stock salt solution comprising the added mineral salts of the substrate was prepared by weighing accurately 2.0 grams KH_2PO_4, 0.2 gram $Ca_3(PO_4)_2$, and 0.2 gram $MgSO_4.7H_2O$. These salts were transferred to a one-liter volumetric flask and diluted to one liter. The flask was shaken vigorously to secure a uniform suspension of the insoluble portion of $Ca_3(PO_4)_2$. Ten (10) ml. of the resulting solution and suspension were pipetted into another one-liter volumetric flask and made up to one liter with distilled water. At this dilution the $Ca_3(PO_4)_2$ is soluble. This dilution is the stock solution used in this study and the concentrations of the salts present are shown in the following table:

KH_2PO_4	20.0 p.p.m.
$Ca_3(PO_4)_2$	2.0 p.p.m.
$MgSO_4.7H_2O$	2.0 p.p.m.

The glucose solution was made up to contain exactly one gram of sugar per liter, or 1 ml. = .001 gm. glucose.

The $(NH_4)_2SO_4$ solution was prepared in a similar manner and contained one gram of $(NH_4)_2SO_4$ per liter, or 1 ml. = .001 gm. $(NH_4)_2SO_4$. One hundred and sixty ml. of this solution were diluted to one liter and this dilution used as the stock solution, 10 ml. of which contained .0016 gm. $(NH_4)_2SO_4$.

The B.O.D. dilutions were prepared by siphoning approximately two-thirds (400 ml.) of the required seeded bicarbonate dilution water into a one-liter cylinder and then adding 5 ml. of glucose stock solution, 2 ml. of the stock salt solution and 10 ml. of the stock $(NH_4)_2SO_4$ solution. The remainder of the bicarbonate dilution water was then added making the final volume 600 ml. Thorough mixing was accomplished by using a perforated metal plunger. The B.O.D. solution after mixing was siphoned into clean 260 ml. ground glass-stoppered bottles with cupped necks for water seals.

The glucose consumption in the dilutions was followed by using the Folin [3] method of analysis as modified by Stovall, Foote and Nichols.[4]

The utilization of soluble phosphorus was studied using Atkin's Phosphorus Method Modified.[5]

The usage of ammonia nitrogen was determined by direct Nesslerization of the substrate with occasional determination of organic nitrogen by Kjeldahl digestion and distillation.

Experimental Results

The salts used in the substrate and the relative proportions of these salts were selected on the basis of Pasteur's early work on yeast fermentations. The ratio of mineral salts to glucose was made considerably higher than Pasteur used because analysis of the substrate during the course of five-day B.O.D. showed this change to be necessary. The actual mineral salt concentrations in our B.O.D. mixtures, however, were only about one-thirtieth as strong as Pasteur used in his yeast fermentations of seven per cent glucose solutions. The ammonium tartrate of Pasteur's salts was eliminated because of its oxygen demand and in its place ammonium sulphate was introduced to supply the nitrogen.

The experimental results which follow will be seen to consist of explorative procedures and in Table I are shown the results using only one component of the salt mixture as a supplementary ration to the glucose in the B.O.D. set-ups using bicarbonate dilution water.

In Table I it is noted that the five-day B.O.D. of the glucose solution using seeded bicarbonate dilution water (distilled water plus 300 p.p.m. of sodium bicarbonate) averaged 218 p.p.m. The five-day B.O.D. of the same glucose solution using the same seeded bicarbonate dilution water but supplemented by the various salts in the concentrations shown are also low values, ranging from an average of 144 p.p.m. for the $MgSO_4$ containing set-up to 198 p.p.m. for the B.O.D. containing $(NH_4)_2SO_4$. It will be observed that the three B.O.D. results from

TABLE I.—*B.O.D. of Glucose* Using Bicarbonate Dilution Water Alone and When Supplemented by Mineral Salts*

(Dilution Factor—120)

Dilution Water Used	5 Day B.O.D.			Average
	Series 1	Series 2	Series 3	
Bicarbonate Dilution Water	228	240	186	218
Bicarbonate Dilution Water Plus 0.0067 p.p.m. $MgSO_4$	156	156	120	144
Bicarbonate Dilution Water Plus 0.0067 p.p.m. $Ca_3(PO_4)_2$	180	198	90†	156
Bicarbonate Dilution Water Plus 0.066 p.p.m. KH_2PO_4	156	192	120	156
Bicarbonate Dilution Water Plus 2.66 p.p.m. $(NH_4)_2SO_4$	246	186	162	198
Bicarbonate Dilution Water Plus Above Mineral Salts Combined	498	605	482	528

* Glucose concentration in all B.O.D. = 8.3 p.p.m.

† Result unexplainable.

which the average value of 198 was obtained, vary from 162 to 246 in this case. Similar variations are present between individual values for B.O.D. of other added substances when the respective results of the three series are compared. Regardless of all the care taken in procuring these results these variations occurred. They may be due to differences in the character and viable numbers of bacteria used for seeding or to certain biological growth manifestations often observed but very imperfectly understood. In this connection, it may be stated that seedings varied between 7,000 and 84,000 viable organisms per ml. of B.O.D. mixture between each series. It is natural to presume that this difference was the cause of the variations in results observed but we are by no means certain that this is true.

It is evident from these results that the five-day B.O.D. of the glucose solution is not enhanced materially by supplementing the bicarbonate dilution water with any single one of the salts used. However, the last line in the table shows that when all salts, in the same concentrations, are used to supplement the bicarbonate dilution water, we obtain a five-day B.O.D. of 528 p.p.m., representing nearly normal oxidation. From this it is evident that a combination of these salts is necessary to permit normal oxidation to proceed in the B.O.D. substrate. The question arises, are all of these salts necessary or will a combination of two or three of them serve just as well?

To answer this question we made three separate runs, the results of which are given in Table II. The technique and procedure was the same as that used in the previous runs except that various combinations of salts were used to supplement the bicarbonate dilution water.

In this series the average five-day B.O.D. of the glucose solution, using bicarbonate dilution water was 129 p.p.m., with a low value in Series 3 of 114. The addition of magnesium sulphate and calcium

TABLE II.—*B.O.D. of Glucose* Using Bicarbonate Dilution Water Alone and When Supplemented by Combinations of Mineral Salts*

(Dilution Factor—120)

	Dilution Water Used	5 Day B.O.D.			Average
		Series 1	Series 2	Series 3	
	Bicarbonate Dilution Water	118	156	114	129
A	Bicarbonate Dilution Water Plus 0.0067 p.p.m. $MgSO_4$ 0.0067 p.p.m. $Ca_3(PO_4)_2$	240	120	144	168
B	Bicarbonate Dilution Water Plus 0.0067 p.p.m. $MgSO_4$ 0.066 p.p.m. KH_2PO_4	216	282	216	238
C	Bicarbonate Dilution Water Plus 0.0067 p.p.m. $MgSO_4$ 2.66 p.p.m. $(NH_4)_2SO_4$	206	90	126	141
D	Bicarbonate Dilution Water Plus 2.66 p.p.m. $(NH_4)_2SO_4$ 0.066 p.p.m. KH_2PO_4	462	384	468	438
E	Bicarbonate Dilution Water Plus 2.66 p.p.m. $(NH_4)_2SO_4$ 0.0067 p.p.m. $Ca_3(PO_4)_2$	202	108	150	153
F	Bicarbonate Dilution Water Plus 0.0067 p.p.m. $Ca_3(PO_4)_2$ 0.066 p.p.m. KH_2PO_4	180	156	252	196
G	Bicarbonate Dilution Water 0.0067 p.p.m. $MgSO_4$ Plus 0.0067 p.p.m. $Ca_3(PO_4)_2$ 0.066 p.p.m. KH_2PO_4	174	180	288	214
H	Bicarbonate Dilution Water 0.0067 p.p.m. $MgSO_4$ Plus 0.066 p.p.m. KH_2PO_4 2.66 p.p.m. $(NH_4)_2SO_4$	472	384	450	435
I	Bicarbonate Dilution Water 0.0067 p.p.m. $Ca_3(PO_4)_2$ Plus 0.066 p.p.m. KH_2PO_4 2.66 p.p.m. $(NH_4)_2SO_4$	484	396	456	445
J	Bicarbonate Dilution Water 0.0067 p.p.m. $MgSO_4$ Plus 0.0067 p.p.m. $Ca_3(PO_4)_2$ 2.66 p.p.m. $(NH_4)_2SO_4$	126	108	150	129
K	Bicarbonate Dilution Water 0.0067 p.p.m. $MgSO_4$ Plus 0.0067 p.p.m. $Ca_3(PO_4)_2$ 0.066 p.p.m. KH_2PO_4 2.66 p.p.m. $(NH_4)_2SO_4$	540	427	480	482

* Glucose concentration in all B.O.D. = 8.3 p.p.m.

phosphate increased results slightly, as occurred with all the other combinations of two with the exception of ammonium sulphate and mono-potassium acid phosphate. When these two were used (*D*) the five-day B.O.D. was 438 p.p.m. Combinations of three (*H* and *I*) gave practically the same values as (*D*). When all four of the salts were used (*K*) a B.O.D. of 482 p.p.m. was obtained, a significant increase over any other value shown in this table but lower than the average value shown for the same dilution water in Table I.

In a further attempt to show the necessity and to justify the use of these salts, a series of runs were made in which duplicate B.O.D.'s were

TABLE III.—*A. Daily B.O.D. and Bacterial Count in Dilutions Using Supplemented Bicarbonate Dilution Water plus 8.3 p.p.m. Glucose.*

Day	Series (1–11)	1	2	3	4	5	6	7	8	9	10	11	Ave.
1st	B.O.D.	0	6	6	6	6	6	41	0	30	42	12	14
	Bacterial count × 10^3	8	3.5	4	35	7	5.4	350	1.3	126	280	25	77
2nd	B.O.D.	72	6	60	120	48	12	306	30	120	216	132	102
	Bacterial count × 10^3	1050	77	1750	1750	1750	110	2400	2.7	1050	4200	1700	1440
3rd	B.O.D.	276	150	276	348	372	132	420	114	270	306	306	270
	Bacterial count × 10^3	2000	2100	2000	2100	2800	1050	1400	1400	2400	3500	2150	2082
4th	B.O.D.	450	342	462	516	456	236	486	210	354	384	492	399
	Bacterial count × 10^3	2150	2100	2800	1750	2700	2800	4200	1750	1400	2100	3400	2468
5th	B.O.D.	516	504	600	558	468	348	522	354	378	396	540	471
	Bacterial count × 10^3	4200	2450	3600	840	2400	3500	3000	3500	1400	4200	3100	2926

B. Daily B.O.D. and Bacterial Count in Dilutions Using Bicarbonate Dilution Water plus 8.3 p.p.m. Glucose.

Day	Series (1–5)	1	2	3	4	5	Average
1st	B.O.D.	12	6	30	18	12	16
	Bacterial count × 10^3	25	5	49	100	84	53
2nd	B.O.D.	36	6	24	24	12	20
	Bacterial count × 10^3	250	53	70	150	105	125
3rd	B.O.D.	30	36	36	36	42	36
	Bacterial count × 10^3	180	75	20	120	90	125
4th	B.O.D.	54	30	30	48	48	42
	Bacterial count × 10^3	240	60	84	105	63	97
5th	B.O.D.	90	54	48	54	60	61
	Bacterial count × 10^3	200	7	75	70	63	83

set up covering a five-day period. One pair of samples, duplicates, was removed from the incubator daily and analyzed for their content of oxygen, glucose, ammonia and phosphorus. Bacterial counts were also made. The results are shown graphically in Figures 1 and 2 and are tabulated in Tables III and IV. The highest individual B.O.D. using glucose with unsupplemented bicarbonate dilution water in Table III (*B*) is 90. Comparing the glucose utilization of the latter four series of this table with the B.O.D. results as shown in series (1–4) inclusive in Table IV (*B*) we see that highest results for B.O.D. corresponds with highest glucose utilization but the amount of oxygen and glucose used is insignificant in every case.

In Figure 1, the curves obtained using the bicarbonate dilution water in general parallel each other, that is, an increase in bacterial growth is accompanied by a proportional increase in oxygen and glucose consumption. The important fact concerning these lower curves is, however, the extremely low rate of bacterial reproduction and low oxygen utilization. With the bicarbonate dilution water, the bacterial count increased only from 53,000 per ml. on the first day to a maximum of 125,000 on the third day, an increase of but 2.4 times. With the water supplemented by the four mineral salts, the curves also parallel each other in a general way, but the values obtained are strikingly higher. The bacteria multiplied from 77,000 per ml. on the first day to 2,926,000 on the fifth day, a forty-fold multiplication. This bacterial

TABLE IV.—*A. Glucose, Phosphorus and Nitrogen Utilization in B.O.D. Mixtures Using Bicarbonate Dilution Water Supplemented by Mineral Salt Mixture*

Results in Parts per Million in B.O.D. Mixtures

	Day	Series 1				Series 2			
		Glucose	PO_4 P	NH_3 N	B.O.D.	Glucose	PO_4 P	NH_3 N	B.O.D.
Present at Start	0	8.3	0.017	0.56	—	8.3	0.017	0.56	—
Found Present by Analysis	1	8.0	0.01	0.28	41	8.5	0.02	0.44	0
	2	2.5	.001	0.22	306	8.5	0.01	0.44	30
	3	1.0	0	0.2	420	7.5	.002	0.38	114
	4	0	0	0.2	486	6.5	0	0.32	210
	5	0	0	0.14	522	4.3	0	0.30	354

		Series 3				Series 4			
Present at Start	0	8.3	0.017	0.56	—	8.3	0.017	0.56	—
Found Present by Analysis	1	8.5	0.017	0.34	30	7.8	0.017	0.32	42
	2	6.2	.002	0.18	120	4.2	0.005	0.2	216
	3	2.2	.002	0.06	270	1.8	0.001	0.08	306
	4	0	.002	0.03	354	0	0.001	0.04	384
	5	0	0	0.03	378	0	0	0.02	396

B. Glucose Utilization in B.O.D. Mixtures Using Same Bicarbonate Dilution Water (Unsupplemented)

	Day	Series 1		Series 2		Series 3		Series 4	
		Glucose	B.O.D.	Glucose	B.O.D.	Glucose	B.O.D.	Glucose	B.O.D.
Present at Start	0	8.3	—	8.3	—	8.3	—	8.3	—
Found Present by Analysis	1	8.5	6	8.5	30	8.5	18	8.5	12
	2	8.5	6	8.3	24	8.0	24	8.0	12
	3	8.5	36	8.2	36	7.8	36	7.8	42
	4	8.3	30	7.5	30	7.6	48	7.8	48
	5	8.0	54	7.3	48	7.5	54	7.1	60

activity resulted in a five-day B.O.D. of 471 p.p.m. and a glucose utilization of 7.3 p.p.m. as against the five-day B.O.D. of 61 p.p.m. and a glucose utilization of 0.9 p.p.m. for the same dilutions without the supplementary mineral salts

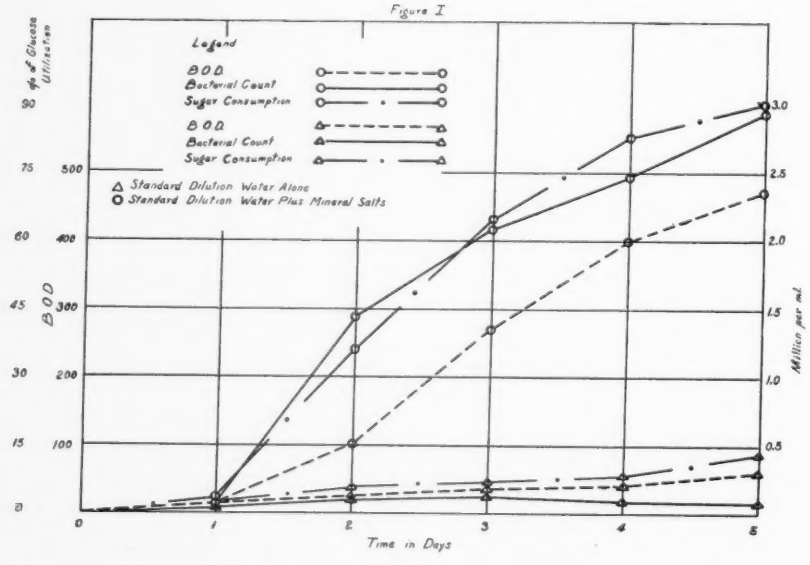

FIG. 1

In Figure 2 the curves of utilization of soluble phosphorus and ammonia nitrogen show a lag on the first day but between the first and third days the slopes of the curves are steeper than in any other two-day interval, indicating that the greatest bacterial activity occurred during this period. Practically all of the phosphorus was used up by the third day, yet addition of 0.02 p.p.m. of phosphorus to duplicate samples at this stage resulted in no increase in B.O.D. Likewise, increasing the original concentration of phosphorus ten times to 0.2 p.p.m. as P produced no significant change. In these dilutions, containing 0.20 p.p.m. of phosphorus, the average residual soluble phos-

phorus on the fifth day was 0.17 p.p.m., a utilization of but 0.03 p.p.m. From these results it is quite evident that only a very small quantity of phosphorus is needed in B.O.D. dilution water.

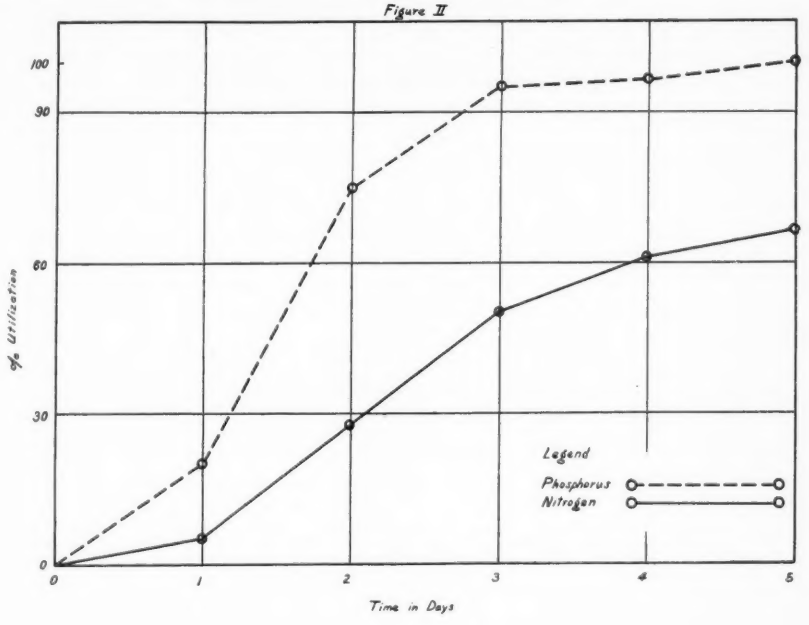

FIG. 2

The nitrogen concentration used was based upon a former study [6] of carbon-nitrogen ratios and in this study was fixed at eleven to one, a favorable ratio. From the curve in Figure 2 it is seen that only 66.6 per cent of the ammonia nitrogen is utilized. This leaves a residual of one-third the total amount originally present. No study was made of the effect of reducing the nitrogen concentration below that which was used (0.56 p.p.m. as N). A study was made of the utilization of ammonia nitrogen because of the possibility of oxygen utilization by the added ammonium sulphate. Three series of samples of five sets of five bottles each were prepared, three of each set containing glucose and two only the supplemented bicarbonate dilution water as blanks. In Table V are given the results of analyses for nitrogen as nitrate, nitrite, free ammonia and organic nitrogen on the samples.

It may be seen from this table that there was no oxidation to nitrite or nitrate. From the decrease in free ammonia we conclude that the ammonia was utilized solely as a body building material by the bacteria in their growth. Observation made in one instance up to thirty days has shown as high as 0.1 p.p.m. nitrite nitrogen but this value dropped to .06 shortly thereafter. The nitrate nitrogen at the end of thirty days had reached a value of .03 p.p.m. In eighteen days the value for nitrite nitrogen was .04 p.p.m. and the nitrate nitrogen was

TABLE V.—*Nitrogen Utilization*

Results in Parts per Million

	Day	B.O.D.	Bacterial Count $\times 10^3$	Nitrogen as				Sugar	PO_4 as P
				Free NH_3	Nitrite	Nitrate	T.O.N.*		
Series I	0		65	0.5				8.3	.02
	1	30	125	0.5	0	0	—	8.0	.02
	2	438	2800	0.46	.001	0	—	1.2	0
	3	480	3500	0.46	.003	0	—	1.0	0
	4	510	4200	0.40	.006	0	—	1.0	0
	5	552	3800	0.28	.006	0	0.24	1.0	0
Series II	0		25	0.44				8.3	.02
	1	0	500	0.44	0	0	—	8.3	.02
	2	104	1400	0.44	.001	0	—	7.0	0
	3	132	1700	0.38	.001	0	—	6.0	0
	4	360	2000	0.34	.001	0	—	4.0	0
	5	360	1100	0.34	.001	0	0.13	4.0	0
Series III	0		70	0.56				8.3	.02
	1	186	600	0.46	.008	0	—	5.0	0
	2	288	3500	—	.004	0	—	3.5	0
	3	396	6000	0.32	.006	0	—	2.3	0
	4	492	5200	0.32	.007	0	—	1.8	0
	5	510	7000	0.30	.006	0	0.29	1.0	0

* Total Organic Nitrogen.

less than .02 p.p.m. It seems certain that the use of supplemented bicarbonate dilution water will introduce no errors from oxidation of ammonia for at least the usual five-day period and probably much longer.

PAPER MILL WASTES

In Table VI are shown the B.O.D. of various types of paper mill wastes run with bicarbonate dilution water, and supplemented bicarbonate dilution water.

TABLE VI.—*B.O.D. of Paper Mill Wastes Using Bicarbonate Dilution Water Alone and When Supplemented by Mineral Salts*

Type of Paper Mill Waste	B.O.D. Using Bicarbonate Dilution Water P.P.M.	B.O.D. Using Supplemented Dilution Water P.P.M.	Increase Using Supplemented Dilution Water Per Cent
Main Sewer	13	35	169
White Water	18	33	83
White Water	25	62	148
White Water	25	73	192
Bleach Plant	30	148	393
Wet Room	50	95	90
Main Sewer	17	44	159

It is evident from the above figures that the use of the mineral salts as a supplement to bicarbonate dilution water resulted in very substantial increases in the five-day B.O.D. of the paper mill wastes examined. Use of this supplemented dilution water on malt-house waste showed an increase of only from 10 to 18 per cent but the B.O.D dilutions were found to have a sufficient phosphorus and nitrogen content for bacterial growth as determined by analyses of the B.O.D. dilutions.

Discussion

The data presented show that a greater consumption of oxygen occurred when certain mineral salts were present. Cooper and Read [7] found sewage to contain phosphate phosphorus in amounts varying from 2.0 to 7.6 p.p.m. An average B.O.D. dilution of this sewage would still contain more than the minimal quantity (.02 p.p.m.) used in our studies. If all sewage contains a like complement of phosphate phosphorus no supplementary phosphate salts would be needed with the bicarbonate dilution water. With reference to stream conditions, Pearsall in 1930 [8] gives figures indicating that the phosphate content of "very clean" stream waters varies between 0.01 to 0.06 p.p.m. expressed as KH_2PO_4. Greaves and Hirst in 1919 [9] report the presence of from 0.72 to 5.47 p.p.m. of phosphorus in ten of the largest streams in Utah. Birge and Juday,[10] however, report the absence of phosphorus in 9 out of 479 Wisconsin lakes. The highest concentration of soluble phosphorus found was 0.015 p.p.m. with the mean having a value of 0.003 p.p.m. On the other hand these workers report an average value for organic phosphorus of 0.02 p.p.m. and there seems to be little doubt but that this organic phosphorus would be usable for bacterial growth and therefore oxygen utilization. In our work we found that the phosphorus present in commercial peptone supplies the demand for this element in B.O.D. mixtures deficient in phosphorus.

It appears therefore, that if a B.O.D. result is to be comparable to the natural oxidative rate either the waste tested must carry its complement of phosphorus or it must be supplied as a supplementary salt to the B.O.D. mixture. With reference to nitrogen, natural waters require only a total of approximately 0.34 p.p.m. of nitrogen either as free ammonia or organic nitrogen to satisfy the optimal oxidative conditions in B.O.D. mixtures.

In order to satisfy the mineral requirements of biological oxidation of all types of sewage and industrial wastes mixtures it seems rational to supplement the present bicarbonate dilution water with adequate amounts of mineral salts shown to be necessary for normal bacterial activity under the conditions imposed in B.O.D. determinations. We propose that the present bicarbonate dilution water be supplemented by mineral salts. As a matter of convenience, we suggest the following method for preparing the supplemented dilution water:

1. Dry Mineral Salt Mixture.

Ammonium sulphate	25.0 grams
Tribasic calcium phosphate ($Ca_3(PO_4)_2$)	0.1 grams
Magnesium sulphate ($MgSO_4.7H_2O$)	0.1 grams
Mono-potassium acid phosphate (KH_2PO_4)	1.0 grams

Grind in a mortar the mono-potassium acid phosphate, tri-calcium phosphate and magnesium sulphate until an intimate mixture is produced. Add the ammonium sulphate in small quantities and mix thoroughly until a homogeneous salt mixture is produced. To prepare:

2. Stock Salt Solution.

Dry mineral salt mixture	0.25	grams
Sodium bicarbonate	30	grams
Distilled water enough to make	1000	ml.

Mix and dissolve.

This stock salt solution is diluted further to make:

3. Supplemented Dilution Water.

Stock salt solution	100 ml.
Distilled water to make	10 liters

This supplemented dilution water will be found to vary only slightly from that used in the above experimental work and to have the concentrations of salts as shown in the following tabulation:

Ammonium sulphate	2.5 p.p.m.
$Ca_3(PO_4)_2$	.01 p.p.m.
$MgSO_4.7H_2O$	.01 p.p.m.
KH_2PO_4	0.1 p.p.m.
$NaHCO_3$	300.0 p.p.m.

Summary

The results obtained in the experimental work reported in this study indicate that:

1. The five-day B.O.D. value of a 0.1 per cent pure glucose solution obtained by the dilution method using seeded bicarbonate dilution water is far below the value obtained using more complex synthetic water.

2. The addition of 2.66 p.p.m. $(NH_4)_2SO_4$ and 0.066 p.p.m. KH_2PO_4 to the bicarbonate dilution water results in a more nearly normal rate of oxidation of glucose in B.O.D. dilutions.

3. The addition of four salts $MgSO_4$, $Ca_3(PO_4)_2$, KH_2PO_4 and $(NH_4)_2SO_4$ having a total concentration of 2.739 p.p.m. to bicarbonate dilution water renders it a far superior medium for biochemical oxidation.

4. The range of phosphorus utilization during the course of the five-day B.O.D. of glucose in these tests was from 0.02–0.03 p.p.m. as P.

5. The reduction of ammonia nitrogen during the five-day B.O.D. was about 0.34 p.p.m. as N.

6. A supplemented bicarbonate dilution water is proposed.

The writers wish to express their appreciation to Miss V. E. Vincent, Assistant Bacteriologist of this laboratory for the bacteriological work reported here.

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Plant Operation

THE CEDAR RAPIDS SEWAGE TREATMENT PLANT

By John C. McIntyre

Plant Engineer

Cedar Rapids, a city of 60,000 population, is located in the eastern central part of Iowa. The Red Cedar River, the flow of which is approximately 650 cu. ft. per second 95 per cent of the time, divides the city very nearly at its north and south center line.

The sewerage system is of the separate type, the treatment plant receiving only the sanitary sewage (plus packing house wastes). The normal average daily flow is 6,000,000 gallons of domestic sewage and 1,500,000 gallons of packing house wastes. Due probably to several large food product plants, the population equivalent of the combined flow, based on flow and B.O.D., is approximately 178,000.

The treatment plant is located on the western bank of the river two miles downstream from the center of the city.

The work preliminary to the actual plant construction was started in 1929 with the construction of a 48-in. East Side interceptor at a cost of $293,887. This was followed in 1931 by the construction of a river crossing, West Side interceptor and pumping plant at a cost of $124,051.

In December, 1933, with the aid of P.W.A. funds, the treatment plant proper was started. This was finished in August, 1935, at a cost of $683,129.

The plant is designed as a sedimentation plus separate sludge digestion plant, including, coarse screening, grit removal, grease removal, primary sedimentation, sprinkling filters and secondary sedimentation (Fig. 1). The packing house wastes are treated in a chemical pre-treatment plant before entering the domestic sewage channels. The pre-treatment plant includes grease removal, primary sedimentation, quick mix with chemicals, flocculation and secondary sedimentation.

Two 30-in. cast-iron siphon lines carrying the domestic sewage across the river from the East Side interceptor and the 42-in. concrete West Side interceptor, join at the plant site in a 15-ft. square concrete chamber. This chamber is directly under the screenings incinerator building, the flow line of the sewage being 24½ ft. below grade line. A mechanically raked screen is located in this building and chamber. The bar spacings of the screen are 1-in. and the raking mechanism is of the endless chain type manufactured by the Chain Belt Company. The screenings are dropped by the rakes into a hopper directly over the incinerator. After draining, the screenings are dumped into the charging door of the digestor-gas fired incinerator. The sewage flows from

this screen through 160 ft. of 48-in. concrete pipe to the wet well of the pumping plant.

FIG. 1.—Aerial view showing the entire plant.

The pumping plant is a two-story building 36 ft. wide and 72 ft. long (Fig. 2). A laboratory and office are located on the second floor, an operators' locker room, transformer room and motor control panels are on the first floor. In the basement, 30 ft. below grade, are four raw

FIG. 2.—Power house at right, main pumping plant and grit remover building at left.

sewage lift pumps. These pumps are of the centrifugal type made by the Economy Pumping Machinery Company. These pumps have a combined capacity of 25,000 gal. per min. against a 40 ft. head. The

pumps have their suction in a wet well 6 ft. wide, 11 ft. high and 60 ft. long. The discharge is through a 48 in. by 24 in. venturi tube and thence 40 ft. up through a 4 ft. square vertical shaft to the grit chamber, from which the sewage flow is by gravity through the rest of the treatment plant.

The grit chamber is 22 ft. square located in a building adjacent to the pumping plant. In this building is also located a garage, storage room and small work shop. The grit is removed continuously with a Dorr Detroiter, washed and dumped into a loading hopper. A Wallace and Tiernan liquid chlorine feeder is housed in this building, with feed lines going to the grease trap and dosing tank.

FIG. 3.—Experimental sludge beds in foreground, trickling filters in background.

Adjoining the grit chamber building is a grease removal tank 13 ft. wide and 28 ft. long. The grease is forced to the surface of the sewage by means of a system of baffles and air diffused through perforated pipes. The grease is skimmed off the surface and put in covered cans to be disposed of by burning.

Two types of primary clarifiers are used in the treatment process. A Dorr Sifeed clarifier is installed in a 70 ft. octagonal tank 12½ ft. deep at the perimeter. The floor slopes to the sludge suction pipe in the center. Four rectangular tanks, each 17 ft. wide, 65 ft. long and 13½ ft. deep, equipped with Chain Belt straight-line sludge collectors, are operated in parallel with the Sifeed clarifier. The sludge from these clarifiers is pumped to the digestors with two 4-in. Barnes Dorrco sludge pumps.

Two Dorr dosing syphons work together, discharging into a 42-in. concrete feed line to the rotary distributors.

Primary clarified sewage is distributed over eight circular filters through Dorr rotary distributors (Fig. 3). One of the distributor units is made up with aluminum arms and nozzles; the other seven have wrought iron arms with bronze spray nozzles. These filters are 167 ft. in diameter with an average rock depth of 6½ ft. The rock is native limestone, graded very closely in size. At the time this rock was being quarried and delivered one rock inspector was stationed at the quarry and another at the point of delivery. The sodium sulphate test for weathering qualities was run on samples taken from various places in the quarry. Each filter has 14,875 linear feet of underdrains. The bottom half of these underdrain lines is cast in the concrete floor of the filters and the top is vitrified half-tile. The lines terminate at the lower end in an open collection gallery which discharges the filter effluent into the secondary sedimentation tanks.

Four secondary tanks, each 16 ft. wide, 72 ft. long and 13½ ft. deep, are used in the treatment process. Each tank receives the flow from two of the filters. The sludge is removed by a straight-line collector and sludge blow-off system developed by Mr. H. R. Green. This secondary sludge may be pumped directly to the digestors or to the raw sewage channel.

The sludge digestors, four in number, are 60 ft. in diameter, 27 ft. deep at their perimeter and 31 ft. deep at their center (Fig. 4). Two of these are covered with P.F.T. floating covers, one is covered with a 70,000 cu. ft. gas holder and the other is used only as an open storage tank. The three covered digestors are fitted with hot-water heating coils and gas collecting pipes. The open storage tank is so constructed that it may be covered and heating coils may be installed if the capacity is needed. The digestors are heated by circulating the cooling water from the engine through the heating coils. The gas lines, raw sludge lines, digested sludge lines, supernatant lines and heating lines are grouped below grade in a ventilated tunnel 8 ft. wide and 9½ ft. high, which connects all four digestors with the basement of the power house.

A power plant building 36 ft. wide and 62 ft. long houses a gas-engine generator set, a vacuum sludge filter and sludge circulating pumps. The digestor-gas fired engine is a 5-cylinder Worthington, developing 210 H.P. at 300 R.P.M., driving a 150 K.W. General Electric generator. The generator is synchronized with the local power company's line. It is so arranged that the treatment plant may draw power from the company line as well as from the generator, or if the generator output exceeds the plant demand, the excess power is fed into the company's line. The power meters register the K.W.H. the plant draws from the power company, the K.W.H. produced by the generator and the K.W.H. added to the power company's line. The cooling water from the engine may be run through an exhaust waste-heat boiler, a gas-fired auxiliary boiler, or through both boilers, before it is circulated through the heating coils of the digestors. During normal operation the cooling water leaves the engine at about 140° F.

An 8 ft. by 10 ft. Oliver vacuum filter is used to dewater the con-

ditioned digested sludge. Ferric chloride and lime are used as conditioning agents, being added to the sludge in an air-agitated mixing tank on the line to the filter. Filter cake discharges on a belt conveyor which runs out to the dried sludge dump. The vacuum pump, filtrate pump, sludge pump and air compressor are located in the basement of the building, eliminating the noise and congestion in the filter room.

FIG. 4.—Digestors and gas holder in center, part of radial-flow clarifier in right foreground.

After several conferences between the city officials and the packing company officials, an agreement was reached whereby the city would construct and operate a chemical pre-treatment plant for the packing house wastes and the packing company would pay a portion of the cost of the entire treatment plant as well as a monthly rental fee. The packing house being located directly across the river from the city treatment plant, it was a simple matter to pipe the wastes across the river and build the pretreatment plant at the site of the city plant.

A small building 16 ft. square located on the east side of the river houses three vertical centrifugal raw sewage pumps. These pumps have capacities at 50 ft. head of 600, 1200 and 1800 g.p.m., respectively. The sewage from the packinghouse flows from a fine screen through 700 ft. of 24-in. tile to the wet well of the pumping station. The pumps force the sewage up 31 ft. into a 14-in. transite pipe line hung exposed on the underside of a railroad bridge crossing the river. This line, 633 ft. long, joins a 14-in. cast-iron line at the west end of the bridge which carries the sewage 500 ft. to the pre-treatment plant site (Fig. 5).

The plant is designed for a flow of 1000 g.p.m. The flow through the plant is controlled with a rate-of-flow controller operating in con-

nection with a venturi tube. When the flow to the plant exceeds 1000 g.p.m. the excess is bypassed to a 400,000 gallon storage tank. When the flow to the plant is less than 1000 g.p.m. the rate-of-flow controller allows the sewage from the storage tank to go through the treatment process.

A grease trap 14 ft. in diameter and 12 ft. deep removes the grease that is found to be present in such wastes.

FIG. 5.—Pretreatment plant in foreground, showing control building, grease remover, the two clarifiers and flocculator. Main pumping plant at left in the rear and gas holder at right in rear.

Two 50 ft. Dorr Sifeed clarifiers are so constructed that they may be used either in series or in parallel, with or without addition of chemicals. Since both clarifiers are at the same elevation a Turbo quick mix is used as a pump, to overcome the pipe friction, as well as a quick mix for the addition of chemicals.

A 150 gal. rubber-lined liquid ferric chloride feeder, a 150 gal. sulphuric acid feeder and a dry lime feeder make up the chemical dosing apparatus. The feeders are located in a building 34 ft. wide and 40 ft. long, which also houses a dry chemical storage room, two 8000 gal. rubber-lined ferric chloride storage tanks and two 8000 gal. steel sulphuric acid storage tanks. Two 4-in. Barnes Dorreo pumps are used to dump the sludge to the digestors.

A Dorr flocculator mechanism is installed in a tank 48 ft. long, 13 ft. wide and 9½ ft. deep.

The effluent from the plant is pumped to the dosing tank of the city treatment plant with a 6-in. Fairbanks Morse centrifugal pump. At this point the packinghouse wastes join the city sewage and go through the sprinkling filters and the secondary clarifiers.

At the present time the plant is operated as follows: After primary settling chemicals are added in the quick mix, then through the flocculator into the secondary settling tank. All the secondary sludge is returned to the raw sewage and the sludge is pumped out of the primary clarifier to the digestors. The packinghouse plant has not been in operation long enough to obtain any conclusive results.

The entire sewage interceptor system and treatment plant was designed by the Howard R. Green Engineering Company of Cedar Rapids and built under the supervision of the City Engineer, Mr. F. E. Young. The treatment plant is financed by the collection of sewer rentals. Since the water plant is municipally owned the sewer rental fee is collected with the water rental fee. The plant is operated under the jurisdiction of the City Council and the City Engineer.

Notes on Operation

Some of the results of operation of the city plant, from December, 1935, through March 1936, are given in the accompanying tables.

During December, 1935, the plant was shut down four days for inspection and minor adjustments on the mechanically raked screen. During the later part of January and the first part of February, 1936, we had twenty consecutive days when the air temperature was never above zero and on several occasions it reached 31° below zero. At this time there was 34 inches of snow on the ground and the trickling filters

Table I.—*General Plant Data*

1935 1936	Population Equivalent .15 lb. B.O.D. per Cap. per Day	City Flow in Million Gallons	Packing Plant Flow in Million Gallons	Total Flow Treated in Million Gallons	Gas Produced in Thousand Cu. Ft.	Cu. Ft. Gas per Cap.
Dec.	160,000	*5.39	0.49	5.88	116	.72
Jan.	167,600	5.301	0.78	6.08	131	.78
Feb.	169,000	5.48	1.40	6.88	119	.70
Mch.	184,100	9.29	1.39	10.68	127	.69
4 month daily av.	170,200	6.37	1.01	7.38	123	.72

* 27 day average.

Table II.—*Power Data*

1935 1936	K.W.H. Generated	K.W.H. Used by Plant	Load Factor	K.W.H. Purchased	K.W.H. Sold
Dec.	3355	1660	97%	48	1745
Jan.	3500	1870	97%	68	1700
Feb.	2980	2090	80%	455	1340
Mch.	3340	2668	93%	184	900
4 month daily av.	3294	2072	92%	188	1421

TABLE III.—*Utilization of Gas*

1935 1936	Total Gas Produced in Thousand Cu. Ft.	Gas Used in Incinerator in Thousand Cu. Ft.	Gas Wasted in Thousand Cu. Ft.	Gas Used in Engine in Thousand Cu. Ft.	K.W.H. Generated	Gas Used per K.W.H.
Dec.	116	8	8	99.5	3355	29.7
Jan.	131	10	22	99.7	3500	28.4
Feb.	119	10	28	80.3	2980	27.0
Mch.	127	17	20	89.7	3340	26.8
4 month daily av.	123	11.3	19.6	92.3	3294	27.9

TABLE IV.—*Sewage Characteristics*

	5 day B.O.D., P.p.m.				Oxygen Consumed, P.p.m.				Settleable Solids C.c. per Liter				Suspended Solids, Total, P.p.m.				Suspended Solids, Volatile, P.p.m.			
	Raw Sewage	Primary Treated	Plant Final	% Reduction	Raw Sewage	Primary Treated	Plant Final	% Reduction	Raw Sewage	Primary Treated	Plant Final	% Reduction	Raw Sewage	Primary Treated	Plant Final	% Reduction	Raw Sewage	Primary Treated	Plant Final	% Reduction
Dec.	531	484	113	81.5					6.6	.53	1.3	78.7	517	160	151	82.7	397	133	73	82.0
Jan.	421	321	74	82.5	170	97	42	71.6	6.7	.75	1.5	74.7	431	152	127	74.6	355	134	95	76.6
Feb.	427	293	104	75.3	179	107	42	73.4	4.9	.60	.50	87.9	374	138	75	79.4	314	127	68	77.5
March	297	230	56	81.0	148	104	30	79.0	4.6	.70	.80	81.6	367	135	67	80.8	294	118	55	80.6
Av.	418	332	87	80.1	166	103	38	74.7	5.7	.64	1.0	80.7	422	146	107	79.4	340	128	73	79.2

had to be shut down two days because of snow drifting over the filters faster than the sewage would melt it off. Most of our trouble occurred at night when the flow to the plant was low. In February the engine was out of service five days for a thorough inspection, a few minor adjustments and repairs. On inspection the valves seemed to be in fair condition but it was deemed advisable to grind them at this time. After grinding a considerable saving was made in gas consumption.

Taking everything as a whole, considering that all the plant operators were inexperienced and that we operated the plant through one of the most severe winters in the history of Cedar Rapids, all of our difficulties now appear to be of minor importance.

COST RECORDS FOR MAINTENANCE AND OPERATION OF THE WORCESTER, MASS., SEWER SYSTEM AND SEWAGE TREATMENT PLANT *

By John H. Brooks, Jr. and Roy S. Lanphear

Supt. of Sewers and Supervising Chemist, Worcester, Mass.

This paper deals with cost records of the maintenance and operation of the Worcester Sewer Department. The Superintendent of Sewage is charged with the operation of the Worcester Sewer Department, which consists of the maintenance of the sewers, operation of the sewage treatment plant and the construction of all new sewers and extensions.

Each year in the city budget three separate accounts are set up for carrying out these duties, namely, a construction, a maintenance and a purification account. The maintenance and purification accounts by their respective designations clearly indicate their function. A brief description of the construction account is, however, necessary to explain its operation.

This account provides for the general administration of the entire department, the administration of the department yard and the construction of all new sewers and extensions. The functions of general administration and of the construction of sewers require no explanation. There is, however, a need for a clarification of the function of the yard account. Its duties and activities pertain to the general service and supply for the entire department. It is concerned with the procurement, storing and distribution of all materials, tools, and supplies and the maintenance, repair and operation of all motor and construction equipment. All of these facilities are available therefore for the entire operation of the department and require careful consideration in the set-up for the department cost accounting.

The purpose of cost records and any system of cost accounting is to provide the administrative officials with a comprehensive picture of and a real control over the activities of the particular operations to which such records pertain. Such a cost system should provide a regular method for analyzing the record of work accomplished and for compiling its costs. If such records are correct and are properly analyzed the administrative official is able to organize the work efficiently, can better watch its operation and more definitely ascertain if results conform with the original plans and estimates.

In principle there should be scarcely any difference between the management and operation of a municipal department and that of a commercial business. In either case budgets are set up, estimates made and the work carried on quite similarly. Cost records provide the data for preparing intelligent estimates and budgets and furnish

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necessary information for systematic and economical prosecution of the work.

Cost and performance analyses obtained by a proper cost accounting system offer the best objective measures of the wisdom of expenditures and of the effectiveness with which work is performed.

It has been considered by some that the accounting for expenditures is sufficient, that it is comparable to cost accounting. However, under a proper system of cost accounting, expenses must be related to a specific amount of work accomplished on a job. A mere accounting of expenditures simply records what commodities or what services are involved. Some of these expenditures may consist of materials or equipment which are for use on other jobs or in later years. Expense accounting is only concerned in recording income and expenditures, in analyzing types of purchases, while cost accounting deals with the work accomplished by such purchases. Under a cost system only that portion of the expenditures which is consumed in performing a definite amount of work in a definite period of time is considered as cost.

As head of the Worcester Sewer Department it has been my task to adjust the use of labor, materials, and equipment in such a manner as to make possible the performance of certain specific tasks more effectively. The records and cost systems used are designed to indicate three factors of management—adjustment of labor, use of equipment, and purchase of materials—and reduce them to some measurable term so that the final results can be interpreted and controlled.

Careful records of work performed by each crew and each piece of equipment used is kept and the cost distributed to the several operations performed. In addition to the information desired from the labor cost, particular value is obtained from the equipment costs which serve not only to record the performance of a particular machine but also to indicate its condition and to evaluate the items of upkeep, serviceability and operation.

The cost records furnish a rigid control over the handling of materials and supplies and assure that they are properly checked when received and used.

The records assist in determining the most suitable kind of material, help to establish standard specifications and, in the purchase of large quantities, furnish aid in obtaining fair prices and discounts.

The following chart illustrates graphically the various steps in the cost accounting system used by the Worcester Sewer Department. It illustrates how labor, materials, equipment and overhead are recorded and are carried into the final work and cost ledger, from which cost statements are made up into the several unit costs.

Four basic elements of expense enter into the cost of producing a unit of work, namely—*Personal Service, Equipment, Materials and Supplies* and *Overhead.*

Personal Service is principally the direct labor expense of the work performed. The record of this expense is prepared by the foreman in the field in the form of an individual time card for each workman.

CHART I.—*Chart Illustrating the Steps in a Sewer Department Cost Accounting System*

Field Labor Reports—showing hours men work on each public works operation, *i.e.*, kind of work
Daily or Weekly Reports of Equipment Use and Work Done—showing hours each piece of equipment works on each oper.
Reports of Work Done—showing cu. or sq. yrds., tons, or other measurements of operation
Material Requisitions—showing materials used on each operation
Invoices and Payrolls—covering supervision, head, light, telephone, and other overhead expense
Preparation of Payrolls
Posting to Individual Equipment Records to show equipment costs
Credits to Stores and Materials Accounts which control the use of materials and supplies
Weekly Summary of Labor—showing hours and cost entering into each operation
Weekly Summary of Equipment Rentals—showing hours of use and amount to be charged to each operation
Weekly Summary of Work Done—showing units of work accomplished under each operation
Weekly Summary of Materials Used—showing quantity and cost entering into each operation
Overhead Clearing Account—needed to distribute overhead expense to each operation
WORK AND COST LEDGER
A separate sheet or account kept to assemble the cost of labor, equipment, materials and supplies, and overhead for each public works operation
Work and Cost Statements—
showing the total costs, unit costs, work units, man hour production, etc.

On Maintenance, the following times are listed: Accounts Receivable, Con. Catch Basins, Freeing Catch Basins, Cleaning Catch Basins, Repairs Sewers, Repairs Catch Basins, Regulators and Cleaning Sewers.

For Purification, the items are: Total, Grit Chamber, Screen, Imhoff Tanks, Trickling Filters, Secondary Tanks, Sludge Disposal, Laboratory, Real Estate and General.

This record shows the time consumed on each of the several operations performed. They establish each week the record for making the payroll and, after distribution extensions, the record is entered in the proper place in the Work and Cost Ledger.

Included in Personal Service is also the item of indirect labor cost, consisting of executive, supervision, and clerical expense. This item

is handled as a part of the overhead expense being prorated on a man-hour basis of all work performed throughout the entire department.

Under *Equipment*, the cost of operating and maintaining the rolling equipment and construction machinery owned by the department is recorded. These costs are distributed to the various accounts for which the equipment is used on an actual time used, and are charged to such accounts on the basis of hourly rental rates which are designed to

Payroll Number ..... Name ..... Rate .....

Foreman ..... Job ..... Week Ending .....

Sat.	Sun.	Mon.	Tues.	Wed.	Thu.	Fri.	Total Hours	Amount	Operation
									Total
									A—Excavation
									B—Underdrain
									C—Sheath. and Brac.
									D—Laying Pipe
									E—Catch Basins
									F—Manholes
									G—Backfilling
									H—Recond. Sts. Etc.
									J—Job Overhead

cover the operation, maintenance and depreciation costs of such equipment. Weekly equipment reports, and reports on fuel and oil requisitions, repair labor and parts used, furnish the data for the equipment expense which costs establish the hourly rental rates used.

Individual equipment records are kept showing the cost of operating and maintaining each piece of equipment, with a break down to show different items of expense, fuel, repair parts and labor which enter into its operation. It is not intended that earnings in excess of upkeep and operation shall be made.

Weekly Equipment Report Week Ending .....

Equipment ..... No. ..... Rate .....

Construction Job ..... No. .....

Sat.	Sun.	Mon.	Tues.	Wed.	Thu.	Fri.	Total Hours	Amount	Oper. or Acct.
									Totals
									Hours on Job—Not in Actual Use

The daily record of the use of equipment is prepared by the foreman or operator and is submitted weekly and similarly distributed to operations as with the time data. These records after extension and summary are entered into the final work and cost ledger.

Materials are those commodities which become an integral part of the work, such as brick, cement, pipe, etc. Supplies are those consumed when used or those which have a comparatively short life, such as gasoline, fuel, waste, small tools, etc. These items are accounted for by means of requisitions and are charged directly to the several operations or accounts when used. The expense for these items is the first cost plus a fixed differential covering the expense involved by the yard account for handling.

The expense involved in the procurement, storing and distribution of these items is the concern of the yard or store account. Requisitions in duplicate are made for such items, which upon delivery of the articles provide the cost record for charging to the particular job or operation the expense for their use. These cost items together with the equipment rental expense are then made up into a so-called yard transfer which is weekly entered in the work and cost ledger.

General Overhead consists of the indirect services, general office expense, fixed charges and other items of a general nature which cannot be charged against any of the three other items of expense. This general overhead expense through an overhead clearing account is distributed to the various work units on a man-hour basis covering the entire department.

Standard work units which have been established, while not complete in every detail, are sufficient to produce an accurate record of the costs and furnish a comprehensive picture of the several operations. It is recognized that all measures of work done cannot be absolutely accurate, frequently they must be approximated. However, it is found that a reasonable measure of the work done and a fairly reliable cost analysis can be obtained, which is of value in administrating the department.

The following chart of Cost and Clearing accounts is used by the Worcester Sewer Department and covers all of its operations.

COST AND CLEARING ACCOUNTS
CITY OF WORCESTER, SEWER DEPARTMENT

General Administration

1. Superintendent's salary and auto expense.
2. General office salaries.
3. Stationary supplies, subscriptions, and other office expense.
4. Vacation and sick leave.
5. Accident Compensation, Professional services, etc.
6. Traveling expense.
7. Credits for General Administration Distributed to Other Accounts (Overhead Clearing Account—Offset to Accounts 1 to 6).

Yard Administration

21. Salaries of yard office and shipping clerk.
22. General yard service—watchman and general maintenance.
23. Buildings—operation and maintenance.
24. Stationary and supplies and other office expense.
25. Proportion of General Administration Overhead.
26. Shop equipment—maintenance and repairs.
27. Insurance on buildings.
28. Handling and storing materials and supplies.
29. Stores losses.
30. General Repair Service.
32. Credit on heat from Water Department.
33. Credit from Charges for Yard and Handling Costs.

Equipment

51. Operative services.
52. Gasoline.
53. Coal.
54. Lubricants.
55. Repair parts.
56. Tires and other supplies.
57. Repair labor.
58. Outside repairs.
59. Insurance.
60. Depreciation.
62. Proportion of General Administration Overhead.
63. Credits from rentals.
64. Credit to offset depreciation charges.

Stores and Store Expense

81. Materials in stock
    Sewer pipe and fittings, cement, brick, sand, gravel, cinders, manholes and catch basin castings, inlet stones, catch basin traps, manhole steps, jointing compound, jute, sewer cloth, lumber-sheathing, rangers, guard rails.
82. New tools in stock
    Shovels, picks, bars, trowels, spades and drills, axes, hammers, mauls, hook ropes, scrapers, saws, hand pumps, trench jacks and derricks, air hammers, paving breakers and air hose, water pipe, water hose, steam hose and canvas, pails, lanterns, tool boxes, shanties, toilets, batteries.
83. Miscellaneous supplies in stock
    Waste, boots, coats, hats, gloves, mittens, paints, nails and spikes, brushes, brooms, valves, bolts, washers, nuts, rope, cable, steel, iron, powder, exploders, fuse, disinfectant, gasoline, coal, lubricants, kerosene.
84. Equipment parts in stock—Tires, replacement parts, etc.
85. Small tools used (Debit with issue of new tools from stores).

86. Repair and maintenance of small tools.
87. Credit from Rental of small tools.

Purification

101. Grit Chamber.
102. Screens.
103. Imhoff tanks.
104. Trickling Filters.
105. Secondary tanks.
106. Sludge Disposal.
107. Laboratory.
108. Real Estate.
109. General Expense.

Maintenance

151. Sewer Repairs.
152. Sewer Cleaning.
153. Repairs to Catch Basins.
154. Cleaning Catch Basins.
155. Freeing Catch Basins.
156. Repairs to Manholes.
157. Regulators.
158. Work on Brooks and Rivers.
159. Other sewer maintenance.
161. Operation and Maintenance of Gold Street Pumping Station.
162. Operation and Maintenance of Lake View Pumping Station.
163. Operation and Maintenance of Massasoit Road Pumping Station.
164. Operation and Maintenance of Proctor Street Pumping Station.

Construction

201. Construction Jobs

Use a separate job number for each job.

Maintain accounts for as many of the following operations as are needed on each job:

	Work Units
A—Trench Excavation *	Cu. Yds
B—Underdrain	Lin. Feet
C—Sheathing and bracing	Lin. Feet
D—Laying Pipe	Lin. Feet
E—Catch Basins	No. of and Depth
F—Manholes	No. of
G—Backfilling	Cu. Yds
H—Reconditioning Streets and Sidewalks	No. Unit
J—Engineering	No. Unit
K—Job Overhead (Watching, Traffic Control, Timekeeping, charges for use of small tools, etc.)	No. Unit
L—Distributed Overhead	No. Unit

* May be subdivided into A–1 Dirt Excavation, A–2 Rock Excavation, A–3 Quicksand Excavation, when desired.

202. Construction Accounts Receivable (Charge with cost of work done).
203. Accounts Receivable Billed. (Credit with bills rendered if Sewer Department received the revenue.)

The work and cost ledger serves as the assembling point of all the cost records. It is the mainspring of the entire scheme. In it are posted all the labor, equipment, materials and overhead costs together with the units of work performed. Thus it gives practically complete information concerning the work.

Separate sheets are used for each of the several accounts listed on the chart of cost and clearing accounts and for each operation or job. The posting is done each week and is obtained from the summaries of the weekly labor reports, weekly yard transfer record and, in the case of hired equipment, from the invoices covering such expense.

An overhead clearing account is used to make the monthly distribution of general administrative expense to the various accounts involved. This is accomplished by multiplying the administrative cost by a ratio of the particular operation hours to the total operation hours and this amount is added to the particular operation cost.

Work and cost statements based upon these four classifications of items involved—*Labor, Equipment, Materials* and *Overhead,* are prepared from the information collected in the work and cost ledger.

Monthly reports of operation costs for each of the several sewer construction jobs are prepared, listing the costs of the several operations typical of such work. This information comes directly from the work and cost ledger and furnishes a complete picture of the work done and its cost relation to the estimated cost. By proper analysis of the report, excessive costs can be spotted and correction made in the particular operation causing such increase, if such correction is possible.

The several operations performed in the maintenance of the sewer system and operation of the sewage treatment plant, while not in all instances amendable to costs showing work units, are similarly treated.

The various operations of maintenance of sewers are accounted for as set forth in the Chart of Cost and Clearing Accounts No. 151 to No. 164 inclusive.

Except for the cleaning of catch basins, the cleaning of sewers and operation of the pumping stations, no units of cost or distribution of expense is attempted. These operations are routine affairs and do not lend themselves to any worthwhile unit cost consideration.

In the cleaning of sewers a record is kept of the location, kind and size of the sewer, the length cleaned, cubic yards of material removed and the total cost. From these data a unit cost per yard of material removed and cost per lineal foot of sewer cleaned is obtained. As a basis for any efficiency study or program consideration this information has little value.

The operation and maintenance costs of the pumping stations are recorded and show unit costs based on million gallons per twenty-four

hours. These costs are represented by labor, machinery repairs, power bills and building upkeep. Here again, except for the power consumption and machinery repair costs, such information is of little value.

At the sewage treatment plant very complete records are kept of the several operations carried on as indicated in the chart of costs and clearing accounts No. 101 to No. 109. Such units of cost as are applicable to the several accounts are in use—the million gallons of sewage per twenty-four hours, cubic yards of grit, screenings and sludge together with the chemical analysis of the raw sewage and effluent are a matter of daily record—to which labor, material and equipment expense is charged. Unit costs per million gallons or per cubic yard are then determined at the end of the year, based on the total cost of each operation and the total amount of the unit of work accomplished.

COST OF OPERATION OF THE SANITARY DISTRICT OF DECATUR, ILLINOIS

By W. D. Hatfield

Superintendent

The Sanitary District of Decatur was organized in October, 1917, soon after the passage of the Sanitary District Law of 1917 by the Legislature of the State of Illinois. This act authorized the formation of Sanitary Districts, whose function was to collect and purify the sewage of cities and the surrounding territories. The law allows the issuance of bonds in an amount not to exceed 5 per cent of the assessed valuation of the property within the District, and the levying of a property tax, of not to exceed 1/3 of one per cent of the assessed valuation of the District, for operation of the District and for bond retirement. The act further provides for an additional tax of 1/3 of one per cent if authorized by the legal voters of the District.

The first tax levy was made for 1918 and the first money was collected in 1919. In 1920 the voters authorized the additional 1/3 of one per cent. In Table I are found the data on the tax as extended and

Table 1.—*Decatur Sanitary District Levies and Collections*

Year	Sanitary District Levy	Tax Levy Extended by County	Taxes Received by San. Dist.	% Levy Received	Collection		Uncollected		Per Capita Tax Received
					Ion Charges	%	Taxes	%	
	$ 50,000								
1919	54,000								(.84)
1920	179,948			County Records Not Available					(.90)
1921	217,506								(3.00)
1922	215,131	$216,324.03	$208,612.74	96.5	$4,850.88	2.25	$ 2,860.41	1.32	3.48
1923	215,825	217,299.01	208,962.80	96.2	4,859.55	2.24	3,476.66	1.60	3.49
1924	150,600	157,855.33	146,470.30	92.8	3,588.40	2.28	7,796.63	4.93	2.44
1925	148,475	150,950.53	144,235.95	95.5	3,684.16	2.44	3,130.42	2.07	2.40
1926	214,500	218,344.99	208,300.08	95.5	5,012.90	2.29	5,022.01	2.30	3.47
1927	170,071	148,967.36	143,915.75	96.5	3,737.52	2.51	1,314.09	.88	2.40
1928	148,595	150,878.36	145,387.04	96.5	3,780.88	2.50	1,710.44	1.13	2.42
1929	148,725	146,807.77	138,348.81	94.2	3,640.67	2.50	4,818.29	3.28	2.30
1930	144,387	150,877.83	141,124.00	93.6	3,704.81	2.46	6,049.02	4.00	2.35
1931	113,450	116,732.57	103,995.05	89.0	3,019.38	2.59	9,718.14	8.30	1.72
1932	112,550	117,332.45	99,952.39	85.0	2,859.11	2.43	14,520.95	12.40	1.67
1933	113,475	119,871.57	102,326.51	85.5	2,865.59	2.39	14,679.47	12.20	1.70
1934	115,000	—	—	—	—	—	—	—	—

( ) The per capita tax levied is indicated by the parentheses, those without the parentheses are the per capita tax received and expended by the district.

collected since the formation of the District. It is of interest to note; (1) that the tax as extended by the County clerk is usually $2,000 to $4,000 more than our tax levy ordinance and that the costs of collection

run from $2,800 to $5,000; (2) That before the depression the District received about 96 per cent of the extended levy and that since 1929 the collections have rapidly fallen to about 85 per cent in the 1932 and 1933 collections; (3) that the cost of collection varies between 2.25 and 2.50 per cent; (4) and that the uncollected taxes, which range about 2 per cent in normal times, have risen to 12 per cent since 1932.

During the years of interception and plant construction, 1921–23, and of the pre-aeration addition in 1926, the tax levy as extended was about $217,000 and during the other years, to and including 1930 the tax levy was approximately $150,000. Beginning with 1931 and through 1934 the levy as extended has been about $117,000 which has netted the District only about $100,000.

The receipts by the District on a per capita basis have been reduced from $3.49 in 1923 to $2.40 in 1927 and to $1.70 in 1933, a total reduction of 51.3 per cent. How these reductions were made will be discussed later under distribution of costs of the District.

Due to the collection of taxes for two years before construction was started, it was not necessary to issue bonds to the 5 per cent limit. During 1921 and 1922, $860,000 in bonds were issued which amounted to less than 2.5 per cent of the property valuation. These bonds have been retired at the rate of $45,000 per year so that in 1935 there remained a total of $225,000 in bonds to be retired. In 1940 the last payment of $45,000 will be made. The interest between 1935 and the last payment will amount to $30,975 thus making a total yet due on the bonds and interest account of $255,975. Figure 1 shows the gradually decreasing annual bond and interest charge and also the large proportion of the total annual expense which this change occupies.

Summary of Construction Costs

A summary of the total costs to the District for the construction of the intercepting sewers and the sewage treatment plant is given in Table II. These costs are itemized so that the cost distribution to land, construction, consulting engineers, supervising engineers, and miscellaneous items are easily seen. The total costs given in Table II are summarized as follows:

	Total Cost	Per Capita	Per Cent of Total	
(1) Land and right of way	$ 28,699.25	$ .48	1.6	
(2) Intercepting sewers	754,449.32	12.55	42.0	78.7%
(3) Imhoff tank and filters (first plant)	630,407.42	10.50	35.1	
(4) Gas collection and odor reduction	19,870.65	.33	1.1	
(5) Pre-aeration plant	253,181.46	4.22	14.1	
(6) Sludge bed extension	11,508.45	.19	.6	21.2%
(7) Effluent pumping station	34,359.99	.57	1.9	
(8) Storm water and sludge digestion	63,206.45	1.05	3.5	
Total	$1,795,682.99	$29.95	100.0	

The data in Table II show that of the final total costs, the construction costs are about 94 per cent; the consulting engineering costs average 3.07 per cent; and the supervising engineering costs average 2.54 per cent. On most items miscellaneous costs have run less than 1 per cent.

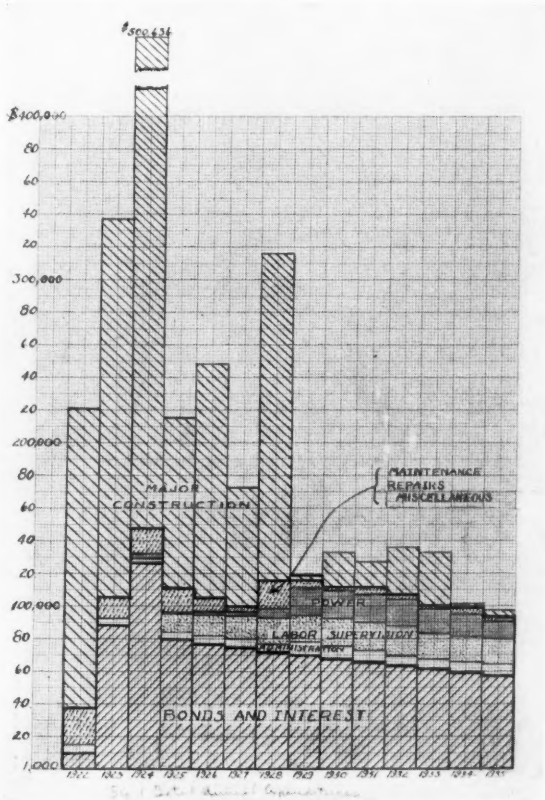


FIG. 1.—Total Annual Expenditures.

The construction costs can also be divided into the cost chargeable to the treatment of the normal domestic sewage from Decatur's 60,000 people and the later additions to the plant which were made necessary because of the unusual trade waste condition, which increased the sewage volume 70 per cent and the population equivalent about the same amount. Items (1), (2), and (3) in the above summary totaling 78.7 per cent should be charged entirely to the treatment of the normal sewage from a city of 60,000. Items (4), (5), (6), (7) and (8) totaling 21.2 per cent, are the additions to the original plant made desirable and necessary because of the industrial waste. The per capita cost indicates an expenditure of about $23.55 for city sewage interception and treatment and about $6.45 additional construction due to the industrial wastes from the starch manufacturing company.

TABLE II.—*Decatur Construction Costs*

	Contract Price	Consulting Engineers	Supervis. Engineers	Misc. Costs	Total Costs	Total
Land and Right of Way						
Old Interceptor					$ 11,869.45	
East Interceptor					1,510.00	
Plant Site					7,531.57	
Roadway to Plant					7,788.23	$ 28,699.25
Intercepting Sewers						
Contract No. 2, Fairview-Plant	$ 187,550.57	$ 6,528.95	$ 5,441.33	$ 1,586.42	$ 201,107.27	
Contract No. 3, S. Main-Fairview	329,204.89	11,269.34	9,457.97	449.50	350,381.70	
Contract No. 4, East Interceptor	134,365.47	3,800.00	4,308.30	1,879.69	144,353.46	
7th Ward Interceptor	19,681.00	651.02	566.00	40.77	20,938.79	
Storm Water Bypass and Overflow	22,894.00	791.57	658.06	35.03	24,378.66	
South Main Pumping Station	12,454.00	641.57	0	193.87	13,289.44	
Total Interception	$ 706,149.93	$23,682.45	$20,431.66	$ 4,185.28	$ 754,449.32	$ 754,449.32
% of Total	93.70	3.15	2.74	.56	100.	
Sewage Treatment Works						
Contract No. 1, Imhoff-Filters	$ 570,707.00	$15,826.05	$16,345.17	$ 425.91	$ 603,302.13	
Power Line to Plant	5,255.25			173.00	5,428.24	
Heating, Plumbing, Admin. Bldg.	1,850.69				1,850.69	
Laboratory Equip. and Apparatus	3,103.82				3,103.82	
Gasoline Locomotive	1,805.00				1,805.00	
Landscape Plans		300.00			300.00	
Deep Well and Water Supply	11,094.37				11,094.37	
Misc. Pumps Etc.				1,059.26	1,059.26	
Office Equipment at Plant				251.41	251.41	
Office Equipment at City				693.50	693.50	
Imhoff Patent Royalties	1,500.00				1,500.00	
Total Original Plant	$ 595,316.12	$16,126.05	$16,345.17	$ 2,620.08	$ 630,407.42	$ 630,407.42
% of Total	94.42	2.56	2.60	.42	100.	
Gas Collectors and Odor Reduction						
Original Construction 1928	$ 15,207.85	$ 1,332.00	$ 243.76	$ 0	$ 16,783.61	
Additional Gas Collection 1929, 1931, 1932	0	0	0	3,087.04	3,087.04	
Total Gas Collection	$ 15,207.85	$ 1,332.00	$ 243.76	$ 3,087.04	$ 19,870.65	$ 19,870.65
% of Total	76.5	6.7	1.2	15.6	100.	
Pre-Aeration Plant (Cont. 5 & 6)						
Pre-Aeration (mostly)	$ 163,355.94	$ 8,411.45	$ 4,447.97	$ 1,571.11	$ 177,786.47	
Blower House (mostly)	44,488.00	239.09	417.39	0	45,144.48	
Equipment for Blower House	26,650.51	0	0	0	26,650.51	
Patent Royalties Activated Sludge	3,600.00	0	0	0	3,600.00	
Total Pre-Aeration	$ 238,094.45	$ 8,650.54	$ 4,865.36	$ 1,571.11	$ 253,181.46	$ 253,181.46
% of Total	94.1	3.4	1.9	.6	100.	
Sludge Bed Extension						
Total	$ 10,241.53	$ 0	$ 868.19	$ 398.73	$ 11,508.45	$ 11,508.45
% of Total	89.1		7.6	.4	100.	
Effluent Pumping Station						
Pump House	$ 19,370.15			$ 26.95	$ 19,397.10	
Pumps and Equipment	11,962.00				11,962.00	
Engineering		$ 1,905.89	$ 1,095.00		3,000.89	
Total Effluent Pumping Sta.	$ 31,332.15	$ 1,905.89	$ 1,095.00	$ 26.95	$ 34,359.99	$ 34,359.99
% of Total	91.1	5.6	3.2	.1	100.	
Storm Water Treatment and Sludge Digestion						
Contract No. 7, Total	$ 56,024.08	$ 3,411.39	$ 1,817.87	$ 453.11	$ 61,706.45	
Patent Royalties	1,500.00				1,500.00	
Total	$ 57,524.08	$ 3,411.39	$ 1,817.87	$ 453.11	$ 63,206.45	$ 63,206.45
Grand Total	$1,653,866.11	$55,108.32	$45,667.01	$12,342.30	$1,795,682.99	$1,795,682.99
% of Total	92.0	3.07	2.54	.69	100.	
Including Land Purchase	93.8					

In connection with the construction costs a few words should be said about the capacity of the structures. The intercepting sewer in the upper stretches is very liberally designed, having a designed capacity of 165 m.g.d. The final section, built in open country and easily duplicated, has a capacity of 40.7 m.g.d.

The sewage treatment plant proper is designed to purify a normal

sewage flow of 10 m.g.d. but has a maximum capacity of between 17 and 18 m.g.d. at times of storm flow. The excess storm water above 18 m.g.d. (up to the capacity of the intercepter 40.7 m.g.d.) is treated in the storm water tanks which have a minimum retention period of 30 minutes at peak capacity.

The original plant (grit chambers—Imhoff tanks—filters and final sedimentation) was placed in operation in May, 1924. This plant was greatly overloaded due to the phenomenal growth of the local starch manufacturing company during the period of design and construction of the interceptor and treatment plant. During 1924, 1925 and 1926 numerous small additions were made but the major work was with the pre-aeration testing station, in experimental studies of methods of treatment of the unusual industrial waste. This culminated in the construction of the pre-aeration plant during 1927.

The construction of this addition was the outgrowth of the experimental studies and an agreement with the starch manufacturing company. The company agreed to reduce the strength of the plant wastes so that the combined strength of city sewage and starch waste arriving at the plant would be reduced from a population equivalent of 350,000 to 150,000, and the Sanitary District agreed to build the aeration plant, thus increasing the plant capacity from a liberally designed capacity of 60,000 to 150,000 population equivalent. The starch company also agreed to improve the recovery process as rapidly as possible, thus reducing the combined population equivalent below 150,000 thereby leaving capacity in the sewage plant for future growth of the City of Decatur. The pre-aeration plant was placed in operation Jan. 1, 1928. The recovery process of the starch waste became effective in May, 1928. A report on the operating efficiencies of the combined plant from 1928–34 was made to this board in 1934 and published in This Journal **6,** 489–503 (1934).

The efficiencies in purification since 1928 were always good except at times of high water when the level of the river was such as to flood the sprinkling filters. At such times the filters had to be bypassed and the efficiency of treatment fell from between 90–95 per cent to as low as 30–40 per cent. In 1930 an effluent pumping station was built so that the sprinkling filters could be operated continuously throughout the year by pumping the purified sewage into the river during high water. In 1932 a storm water treatment unit, additional sludge digestion and sludge storage tanks were constructed. These additions have made the sewage treatment most complete, allowing 89 to 95 per cent purification at all times and treatment of more storm water than is usually treated in American cities. This very complete treatment has been required (1) because of the very low water in the river in the summer and fall when the flow of water over the Decatur dam is zero and (2) to protect Springfield's water supply when the velocity of flow in the river is high due to moderately high water.

The purification problem is interesting and different from that of many cities. When the river is very low, complete purification of the

sewage is necessary to prevent nuisances and protect fish life in the stream in the first fifteen to twenty-five miles below Decatur. At such times the time of flow between Decatur and Springfiled is between five to seven days and pollution of the Springfield water supply is relatively unimportant because of the natural purification of the stream. At times of high water the time of flow to Springfield is reduced to 18 or 20 hours in which case the plant must function to protect the water supply and not to prevent nuisance and protect fish life.

Distribution of Expenditures

The preceding data have shown that the Sanitary District has invested in land, right of way, intercepting sewers and treatment structures a total of $1,795,682.99 or a per capita investment of $29.95. Also the annual income from taxes has varied from $208,000 in the nineteen twenties to about $100,000 from 1931 to 1933, inclusive.

It will now be of interest to study the cost of operation of the District and to break down that cost into its major and minor divisions.

Figure 1 is a graphic picture of the annual expenditures of the Sanitary District since construction was started in 1921–22. It shows the division of expenditures for major construction, bond retirement and interest, administration, labor and supervision, power, and the group comprising maintenance, repairs and miscellaneous.

The construction costs were largely completed in the fiscal year of 1928. Again in 1930 through 1933 the construction of the effluent pumping station and the storm water treatment plants brought the annual construction costs to $25,000 to $30,000. Since 1933 there have been no major construction costs. The plant now has a capacity to treat the sewage of a population equivalent of 150,000 and with the sewage strength averaging 100,000 to 110,000 there is a reserve capacity of about 40,000 population equivalent for future growth of the city or increase in grind at the starch works.

The peak cost of $126,425 for interest and bond retirement came in 1924, and since 1925 has reduced each year by the sum of $2,175 so that the appropriation this year (1936) was for $55,425. During the last few years, with no construction costs, the bond and interest charge has amounted to about 60 per cent of the total expenditures.

District Operation.—In Figure 1 between the bond and interest cost and the major construction cost will be found what I choose to call the cost of operation including administration, labor and supervision, power and maintenance, repairs and miscellaneous. In 1928–29 this cost of operation increased due to placing the pre-aeration plant in operation. The pre-aeration plant requires a large amount of electric power and this accounts for the increased power costs.

Beginning in 1928 the District was able to treat all the sewage from the city; the cost of operation before that time was not normal. Therefore, Table III was prepared, which shows in itemized form the distribution of annual expenditures of the District beginning with the fiscal year ending April 30, 1929. These data have been obtained from the

clerk's books and from the annual audits. It has not always been possible to separate certain items and to distribute them precisely. However, at the bottom of the table the total accounted for is compared with the total of the annual audit and the deviation has always been less than $600.

TABLE III.—*Distribution of Expenditures*

Fiscal Year Ending Apr. 30	1929	1930	1931	1932	1933	1934	1935
Administration							
Officers' Salaries	$ 525.00	$ 725.00	$ 925.00	$ 925.00	$ 925.00	$ 925.00	$ 925.00
Employees' Salaries	4,220.00	4,255.00	3,790.00	3,268.56	3,075.00	3,030.00	3,030.00
Travel Expense	107.35	140.87	317.80	213.58	15.00	43.53	116.70
½ Telephone-Telegraph	79.01	85.88	84.98	92.68	79.44	78.13	68.54
Extra Legal Services	1,000.00	1,010.24	629.50	475.84	0	200.00	500.00
Office Rent	180.00	180.00	195.00	180.00	180.00	180.00	195.00
Contingent Fund	1,800.00	103.53	250.54	685.95	1,440.04	1,705.28	1,664.87
Total	$ 7,911.58	$ 7,409.52	$ 6,192.82	$ 5,841.61	$ 5,714.48	$ 6,161.95	$ 6,500.11
Bonds and Interest							
Bonds	$ 45,000.00	$ 45,000.00	$ 45,000.00	$ 45,000.00	$ 45,000.00	$ 45,000.00	$ 45,000.00
Interest	26,650.00	23,475.00	21,300.00	19,125.00	16,950.00	14,775.00	12,600.00
Total	$ 71,650.00	$ 68,475.00	$ 66,300.00	$ 64,125.00	$ 61,950.00	$ 59,775.00	$ 57,600.00
Plant Operation							
Labor and Supervision	$ 15,827.56	$ 15,739.56	$ 17,594.07	$ 17,860.12	$ 15,727.32	$ 15,665.79	$ 15,937.97
Power	16,894.10	16,629.30	16,928.85	16,367.96	14,204.21	13,570.83	10,541.54
Equipment and Maintenance	1,230.99	2,455.72	3,298.93	1,380.67	1,280.81	1,287.56	2,073.22
Materials and Supplies	1,705.06	946.42	930.23	1,113.27	661.69	751.56	524.61
Maint. of Roads	0	67.25	25.00	82.00	34.95	14.00	0
Care of Grounds	0	0	382.88	186.98	117.28	123.31	85.45
Publishing and Printing	128.87	113.85	20.75	40.95	31.50	22.75	32.45
Office Supplies	113.48	32.06	81.08	88.15	27.16	52.06	60.83
½ Telephone-Telegraph	79.01	85.88	84.98	92.67	79.44	78.13	68.55
Contingent Fund	259.95	283.80	849.80	258.67	308.93	1,179.88	468.13
Total	$ 36,239.02	$ 36,352.84	$ 40,196.57	$ 37,466.43	$ 32,473.29	$ 32,745.87	$ 29,792.75
Construction Costs							
Engineering Services	$ 15.00	$ 1,032.50	$ 1,995.89	$ 247.50	$ 0	$ 0	$ 0
New Construction	2,969.75	20,124.12	12,594.35	27,422.82	33,076.19	1,470.00	3,516.25*
Contingent Fund	99.60	0	225.47	990.06	219.73	342.54	0
Total	$ 3,084.35	$ 21,156.62	$ 14,815.71	$ 28,660.38	$ 33,295.92	$ 1,812.54	$ 3,516.25
Grand Total Accounted For	$118,884.95	$133,398.98	$127,505.10	$136,092.30	$133,433.69	$100,495.36	$ 97,409.11
Grand Total Annual Audit	118,890.64	132,771.00	127,974.01	136,384.30	133,433.69	100,000.92	97,719.09

The last two items in the table should check, but in a few cases it has been difficult to separate the items in the audit. The error in all cases is a few hundred dollars and amounts to less than 0.6 per cent of the total.

* This item of $3,516.25 was for royalties on the activated sludge unit.

Administration Costs.—The first major classification in Table III is Administration. The only items that vary greatly from year to year are extra legal services and the contingent fund. Extra legal services are due to court cases such as the North Fork Drainage case and the Activated Sludge Patent Suit. The reason for high administration contingent funds in 1929, 1933, 1934 and 1935 is interest on anticipation warrants. Contingent expense on sewers or plant have been charged to plant operation. The item, officers salaries, refers to the trustees and the treasurer.

The largest item, about $3,000, is for employees' salaries, which include the salaries of the clerk, attorney and sanitary inspector on Lake Decatur. The total administration expense was about $6,500 in 1935 or about 6.6 per cent of the total expenditures.

Bonds and Interest.—The second major classification is the bond and interest charge and deserves little additional remarks except that it was about 58.9 per cent of the total expenditures in 1935.

Plant Operation.—The third major classification in Table III is plant operation. The largest item in this classification is "Labor and Supervision." In this item the entire salary of the superintendent has been included although strictly speaking part of this salary should probably be considered as administration. This item consists of the wages of the superintendent, laboratory assistant, foreman, three men on shift as operators and sample collectors, and four men that work as general maintenance labor about the plant and as Sunday, holiday and vacation relief men; a total of 10 men. The operators and laborers (7 men) work on an 8 hour per day—six days per week basis, which with the Sunday relief amounts to 52 to 53 hours per week. They are paid at the rate of $22.00 per week or 42¢ an hour. Four of these men have been with the District since the first or second year of operation. The foreman receives $36.00 a week or 75¢ per hour. He has been with the District since the plant was started. The laboratory assistant is a recent graduate of Milliken University and he receives $25.00 per week. This position has usually been held by college graduates who needed to earn some money to go on to school for advanced work and who have been more interested in the experience than the salary. The superintendent's salary is $4,500 per year. In 1933 all salaries were reduced 10 per cent except those of the trustees which are specified by law. The total amount spent for wages and supervision in 1935 under the item of plant operation was 16.3 per cent of the total district expenditures, and 53.5 per cent of the plant operating costs.

Power.—The power costs are a close second to the labor costs in the plant operation classification. These were over $16,000 for the fiscal years 1929, 1930, 1931 and 1932. Since then it has been possible to reduce this power cost by reductions in rate, by greater experience with the treatment process, because of weaker wastes from the starch manufacturing company, and to the 5-day week under which it now operates. In the fiscal year 1935 the power costs were $10,541.54 or 10.8 per cent of the total District expenditure and 35.4 per cent of the plant operation costs. Thus, power and labor constituted about 27 per cent of the total expenditures and about 89 per cent of the cost of plant operation.

The items under plant operation designated as "Equipment and Maintenance" and "Materials and Supplies," should be grouped together for they are a rather fictitious separation. The sum of these items do not vary greatly from year to year and vary from $2,000 to $4,000. In 1935 this charge was $2,597.83 or 2.7 per cent of the total expenditures, and 8.8 per cent of the cost of plant operation.

Total Cost of Plant Operation

The total cost of plant operation from 1929 to 1932 was between $36,000 and $40,000. Chiefly due to the reduction in power costs but also to a reduction of $1,786 per year in wages the total operation costs

have been reduced to $29,792.75 in 1935. This latter amount is 30.5 per cent of the total expenditures of the District for that year.

It is hoped that the power costs may be reduced to a minimum of from $2,000 to $4,000 a year, either by the present method of operating without the pre-aeration plant, due to more complete recovery of starch wastes, or by installation of a gas engine to run the blowers, if and when the sewage becomes stronger. This will reduce the plant operation charge by $6,000 to $8,000 a year or from 20 to 27 per cent.

Per Capita Expenditures

The cost distribution from Figure 1 and Table III are presented in Table IV on a per capita basis. The administration costs are about 10¢ per capita. This will be reduced as soon as the District can catch up on anticipation warrants. The plant operation costs have been reduced from a maximum of 66¢ to below 50¢ per capita. The bond and interest charge is now below 95¢ per capita and will be zero after 1940 if no further bonds are issued. The major construction costs are now only a few cents per capita and will remain low or zero for some years. The total cost of operating the District in 1934 and 1935 was $1.68 and $1.63 per capita per year respectively.

Table IV.—*Per Capita Cost, Basis Population 60,000*

	Year Ending Apr. 30	Administration	Plant Operation	Bonds Interest	Major Construction	Total Expended	Taxes Received
	1922	$0.082	$0.268	$0.017	$3.170	$3.68	
	1923	.066	.226	1.475	3.91	5.68	
	1924	.036	.351	2.100	5.85	8.35	$3.48
	1925	.066	.378	1.345	1.59	3.45	3.49
	1926	.074	.470	1.284	2.31	4.13	2.44
	1927	.076	.364	1.250	1.20	2.89	2.40
	1928	.076	.648	1.200	3.34	5.25	3.47
	1929	.132	.603	1.192	.05	1.97	2.40
	1930	.123	.605	1.140	.35	2.21	2.42
	1931	.103	.660	1.105	.25	3.14	2.30
	1932	.097	.625	1.067	.48	2.27	2.35
	1933	.095	.541	1.030	.56	2.22	1.72
	1934	.103	.545	.996	.03	1.68	1.67
	1935	.108	.496	.960	.06	1.63	1.70
Per Cent Total, 1935		6.65%	30.5%	58.9%	3.78%	100.0%	

Anticipation Warrants

A word should be said about operation on anticipation warrants and the interest charge resulting therefrom, which is charged under administration in the contingent fund. Until 1933 the District oper-

ated on taxes collected without issuing very many anticipation warrants. In 1932 and 1933 the storm water treatment plant was designed and constructed at a cost of $63,206.45. Money had been accumulated to pay for most of this plant addition but the system of tax collections was changed by state law from collecting most of the levy the first few months of the year to collecting the first half in May, June and July and the second half in August through December. Also the depression struck tax collections in 1932, reducing the District's income $13,000 to $17,000 annually. Since that time, because the bonds for $45,000 and half of the interest ($3,000 to $4,000) had to be met May 1st before any tax monies had been received, anticipation warrants have been necessary throughout the major portion of the year. Each year we have been catching up on warrants at a rate of about $6,000 and with still further economies in plant operation and power costs the District should again be able in a few years to get on a cash basis.

In defence of the taxing bodies it should be said that they are a business operating on the basis of extending credit for about 18 months. Their appropriations and tax levies are made in the summer of one year (with fiscal expenses starting May 1 for the Sanitary District). They begin to get half of their money on which to operate 12 months later and the total is not received until 18 months later. When the Sanitary District gets on a cash basis it will have reached a position where it has saved up its income one year in advance.

Note: The expenditures for the fiscal year ending April 30, 1936, are summarized as follows:

Administration	$ 5,375.93	6.25%	$0.087 per capita
Bonds and Interest	55,425.00	64.75	0.925
Plant Operation	24,857.06	29.00	0.415
New Construction	none	none	none
Total Expenditures	$85,657.99	100.00	$1.427

These figures show a material reduction in each of the main items, and a total reduction of $9,062 from the previous year which amounts to a per capita reduction from $1.63 to $1.43. The reduction was effected largely by the annual decrease in interest charge and by power cost reductions, as anticipated in the above report.

CHEMICAL PRECIPITATION TO MEET DILUTION DEMANDS *

By C. K. Calvert

Superintendent, Indianapolis Sewage Treatment and Garbage Reduction Plants

Chemical treatment of sewage was tried first in 1740 in Paris. Little progress occurred, however, until about 1860. More than 400 patents covering this method of treatment were issued, mostly English, in the ten years preceding 1875. Despite splendid results obtained in laboratory and specially constructed experimental works, full scale installations were failures. While clear effluents were obtained, stability was lacking and the receiving waters continued to be offensive. English government officials repeatedly condemned the various chemical methods as being insufficient, but local authorities frequently were impressed with misleading propagandism on behalf of chemical methods and, in the face of the failure of one process, fell before the claims of a new method. Salford tried thirteen, Birmingham seven and most large English towns had at least one similar experience. A few German cities tried chemical precipitation and in each case the opinion of the English Commission was confirmed.

Of the chemicals proposed, lime was included most frequently, with aluminum and iron salts close seconds. Patents called for the use of herring brine, house ashes, china clay, vitriol, tar, coal dust, zinc salts and a whole host of substances alone and in combination. One early patent required the use of thirteen items.

An objection to the process frequently mentioned in connection with the operation of the older plants is the difficulty experienced in sludge disposal. The promoters represented the sludge as being valuable and salable as fertilizer but it met with cool reception from the agriculturalists and attempts to dry it for more convenient handling proved to be costly. While it did contain elements needed by the land, other sources offered just as helpful materials at much lower cost.

Profit vs. Results

In this country as well as abroad many of the proponents of the various chemical methods had more interest in the financial end of the business than in the successful treatment of sewage. This situation caused engineers to give the method a wide berth rather than to study its possibilities. Chemistry, in the minds of non-chemists, is a mysterious thing capable of accomplishing the impossible. Perhaps this is the reason that many city officials are misled by exorbitant claims for chemical treatment. Instead of the use of high-pressure sales methods on non-technical city officials, the proponents of chemical precipitation methods should employ trained and well informed engineers

* Presented before the Twelfth Annual Conference of the Michigan Sewage Works Assn., East Lansing, April 3, 1936.

with chemical experience or background. Only such people are able to determine the applicability of certain treatments to meet the requirements of individual situations.

The revival of chemical treatment is not due to the discovery of a new chemical agent. Practically all, if not all, of the chemicals proposed today are covered by patents many years old. Even pre-sedimentation and the re-use of sludge as a precipitant were covered by patent as early as 1868.

Certainly, chemical precipitation has been encouraged by the low price of ferric chloride and improvement in methods of chlorinating ferrous salts. A particularly important item is the development of equipment and methods for the measurement, handling, and application of chemicals, the removal, dewatering and drying or incineration of sludges, and the proper handling of the treated sewages. All of these have encouraged engineers of ability and repute to investigate the possibilities of chemical treatment to meet the conditions of load and diluting water that are imposed in the various cities and towns.

Extent of Sewage Treatment

It is well established that sewage treatment should be carried only to such an extent as is required to meet the demand of the receiving water. There is no need to saddle on a town the cost of a dress-suit plant to be used only for a stort time each year if a plain durable business suit plant will meet the situation. Interest and depreciation, with obsolescence, are a continuous burden and constitute a much larger expense item than most plant superintendents and city officials allow themselves to think.

If the receiving water is used as a source of municipal supply, or if recreational facilities are involved, a much more complete treatment is required than is needed if only common nuisance is to be avoided. If the effluent goes into a lake in such a way as to prevent reasonably rapid mixing, a higher degree of treatment will be necessary to avoid complaint than if currents offer a large amount of diluting water. Sluggish streams, which provide opportunity for the deposition of solids, can remain aerobic in a given time of flow only with a much lower sewage load than shallow, rapidly flowing streams with plenty of riffles. Permissible loadings change from season to season. Stream stages are uniformly lower in summer than during the rest of the year and the lower oxygen content and accelerated rate of oxygen demand at elevated temperatures operate to make summer an especially severe season. Where extensive sludge banks may form, winter operation cannot be slighted since, as the temperature increases, these deposits will deplete the already deficient summer oxygen supply. While the greatest capacity and highest efficiency may be required for a relatively small part of the year, fixed charges go on continuously. In such situations, chemical precipitation is said to be indicated as a matter of economy and efficiency. When plant loadings increase to a point requiring

complete treatment, most of the chemical precipitation plant can be utilized for treatment preliminary to the final process.

Examples of Chemical Plant Operation

Rather extensive experimental work on chemical treatment is in progress and a number of full-scale plants have been built, some of which have been operated long enough to give performance and cost data. A brief review will give an indication of what can be and has been accomplished.

The Dearborn plant was one of the first large plants of the chemical precipitation type. It has been studied extensively by a number of investigators and numerous reports published. The use of magnetite filters and the practice of treating the sludge from another sewage plant in addition to its own, complicates the study of results, in so far as chemical precipitation is concerned. One of the magnetite equipped settlers, with a capacity of 4 m.g.d., is used for sewage. From April, 1935, to February, 1936, inclusive, a period of 335 days, raw West Side sewage was treated at an average rate of 2.61 m.g.d. using 250 lb. of lime and 305 lb. of $FeCl_3$ per m.g. The raw sewage contained 293 p.p.m. suspended solids and the B.O.D. was 174 p.p.m. Reductions, including the filter, were 92 per cent and 76 per cent respectively. Formerly, paper pulp was used but has been discontinued. Sludges obtained from this process and from the East Side Imhoff plant are filtered and incinerated.

The Perth Amboy plant is equipped to apply lime, iron and paper pulp, flocculate with air, settle, and filter through magnetite. The sewage is predominantly industrial and varies enormously in pH and load. Tests made in July and August 1935, using about 650 lb. of lime and 250 lb. of $FeCl_3$ per m.g. and with 3.5 hours detention before filtering, on sewage with 240 p.p.m. suspended solids and 257 p.p.m. B.O.D., showed reductions of 88 per cent and 61 per cent respectively. The cost of chemicals was about $8.00 per m.g. Only one of the two filter-equipped settlers was used and it was operating at about 50 per cent capacity. The plant was built to treat 10 m.g.d. and is reported to have cost $375,000. The receiving water at Perth Amboy requires only preliminary treatment to avoid nuisance.

Testing station experiments were made at Coney Island using increasing amounts of chemicals on sewage of about 125 p.p.m. suspended solids and 150 p.p.m. B.O.D. A suspended solids removal of 38 per cent and a B.O.D. removal of 25 per cent were obtained without chemicals, which removals were increased to 93 per cent and 78 per cent, respectively, with 1015 lb. of lime and 361 lb. of $FeCl_3$ per m.g. The detention period was about 2 hours. These removals were increased by filtration through magnetite and with material reduction in chemicals applied.

Experimental work carried on in 1933 at Grand Rapids was followed by a pilot plant in 1934 and 1935. As a result of this work it is decided that chemical precipitation will relieve the objectionable con-

ditions in the Grand River at lower initial and operating expense than biological methods. The cost of additional construction is estimated at $75,000. It includes a chemical house and mixing compartment to treat an average of 24.7 m.g.d. Treatment will consist of the addition of 160 lb. of $FeCl_3$ per m.g. with 15 minutes mixing and 2 hours sedimentation. This treatment will be applied for 16 hours per day on 184 days per year. Two additional laborers will be required. Removals are estimated as follows:

	Per Cent		
	Plain Sedimentation	Chemical Precipitation	P.P.M. Raw Sewage
Suspended Solids	55.4	75.8	202
B.O.D.	40.6	48.7	214
Chlorine Demand	18.2	25	22

It is estimated that chemical treatment will increase the present daily dry sewage solids recovery of 25,000 lb. to about 37,000 lb. It is expected that the increase in solids recovered will mean an added income from sales of "Rapidgro," which is dried digested sludge, although only one third of the production is sold now. It is expected, also, that more gas will be formed in the digestors. The cost of operation is expected to be increased by $2.91 per m.g. for the entire year or $8.34 per m.g. for the sewage actually treated with chemicals, both figures including interest and depreciation on the $75,000 worth of equipment added. This increase amounts to 15¢ per capita per year.

The operation of a semi-portable experimental plant at East Lansing showed that ferric chloride removed an increasing amount of suspended solids up to a dose of 180 lb. per m.g., at least, and the B.O.D figures indicated that organic colloids were removed as well as suspended solids.

One of the most notable chemical precipitation installations is the Shades Valley Plant at Birmingham, Alabama. Regardless of its cost or performance, it is an unusually beautiful plant, well arranged and maintained. It is designed in halves, which operate in parallel as plain sedimentation, during the winter, and either in parallel or series in the summer, with chemical precipitation, for a flow of 2 m.g.d. In 1935, it treated 522 m.g. by plain sedimentation and 93 m.g. by chemical precipitation.

The preferred method of operation, with chemicals, is in series, with the return of chemical sludge to the raw sewage and with slightly overchlorinated copperas added at the end of the first settling basin. It is believed that pre-sedimentation without the return of sludge results in no large saving in chemical. The returned chemical sludge aids in odor control, clears the sludge of acid, saves chemical, allows a heavier sludge to be collected for digestion, smooths out the sewage flow and allows time for laboratory tests before the addition of chemical.

A final sedimentation period of one hour is found insufficient. During the summer of 1935, with an average daily flow of 0.6 m.g., the sedimentation time was 3.33 hours. The rate of chemical application is varied seven times a day, based on flocculation tests. The average application is 480 lb. of copperas treated with 70 lb. of chlorine per m.g., which is equivalent, on an iron (Fe) content basis, to about 300 lb. of ferric chloride.

Chemical sludge digests well in two-stage digestors, the initial one being heated. The supernatant liquor from the second stage has a B.O.D. of less than 100 p.p.m. but contains 200 p.p.m. of ferrous iron which must be chlorinated to prevent its loss in the effluent. The digestors are designed for a connected population three times the present.

During the winter, when plain sedimentation is used, the cost per m.g., including fixed charges (F.C. $9.14, Oper. 11.39) is $20.53 and in the summer, when chemical precipitation is used the cost is (F.C. $35.79, Oper. $17.10) $52.89 or for the year (F.C. $13.17, Oper. $12.25) $25.42. No supervision or laboratory charges are included. The fixed charges per m.g., during operation as a chemical precipitation plant, at a rated capacity of 1.5 m.g.d., will be reduced to $14.79 for the same period of operation as in 1935, making the total cost $31.89. This is considered cheaper for the Birmingham condition than any biological process. The raw sewage averaged 124 p.p.m. suspended solids and 85.5 p.p.m. of B.O.D. Removals averaged, respectively, 92 and 86 per cent.

Effect of Chemicals on Sludge

In studying the results of operation of plants and processes, it is difficult to be sure that all pertinent factors are considered, since the methods of operation, of calculating results, and the ends in view may not be clearly understood . Particularly in the smaller plants, capacities have been designed for much more sewage than is treated at first. This may be on account of uncompleted interceptor construction or liberal allowances for the future, which can be arranged financially in the case of smaller plants much better than for the larger ones. Whatever the reason, frequently, consideration of the results is complicated seriously by the factor of rates of treatment. Most reports include the rates of chemical application and results obtained, insofar as the liquid portion is concerned. If sludge is reported at all, its volume is not given, although Eldridge reports that the addition of sludge from the Grand Rapids municipal softening plant increased the sludge solids 2 times and the volume 1.5 times. This item is just as important as the moisture per cent and its omission prevents a consideration of one of the most difficult phases of sewage treatment, namely, sludge disposal.

Obviously the use of chemicals increases the volume and weight of sludge solids to be handled. Very little information is found to show what effect chemicals may have on the water within the sludge particles themselves. The use of a number of chemicals on the sludge, after its removal from the sewage, affects its ability to hold water.

Some of them dissolve out mineral matter leaving a sludge with less ash than it had originally. The concentration of chemicals in sewage treatment is very much less than in sludge being conditioned for filtration and it seems doubtful that actual dewatering of sewage solids occurs in the usual chemical precipitation process. However, the experiments at Dearborn and at Grand Rapids both showed better coagulating results with ferric chloride than with ferric sulphate. In this connection, Eldridge has suggested that the sulphate may have a peptizing action on sewage solids.

Theoretical Chemical Sludge Composition

When lime is added to sewage, in hard water territory, the calcium bicarbonate is precipitated as calcium carbonate along with the calcium in the calcium hydrate added. Disregarding the free CO_2, and assuming that the lime used contains 10 per cent solid inert matter, it is calculated that for every 100 lb. of hydrated lime added there is precipitated about 250 lb. of dry solids. This material is in condition to act as a coagulant to some extent. If all of it goes out of suspension with the sludge, it adds volume and weight to the dry solids removed and increases the water in the sludge which must be handled. For instance, Indianopolis primary sludge dry solids amount to about 900 lb. per m.g. The sludge is removed with a moisture content of 95 per cent which amounts to 17,100 lb. of water. If the sewage were treated with 500 lb. of lime the solids would be increased from 900 lb. to 2165 lb. per m.g., and the water contained, assuming that the sludge could be drawn at 10 per cent solids instead of 5 per cent, would be about 2400 lb. per m.g. more than in the sludge from plain sedimentation. Disregarding the extent of sewage purification resulting from such treatment, the problem of handling 2.5 times the usual weight of sludge solids or evaporating 14 per cent more water, is a serious matter, so far as operation costs are concerned. In order to compensate for this expense, there must be large advantages not easily apparent. The sludge problem is especially formidable when it is remembered that experimental treatment of Indianapolis sewage at the rate of 3000 lb. of hydrated lime, along with 70 lb. of ferric chloride per m.g. effected a B.O.D. removal of only 25 per cent more than plain sedimentation.

The effect of ferric chloride on sludge volume is difficult to determine. In the laboratory it is hard to concentrate ferric hydroxide to a greater solids content than 1 per cent. Loading it with calcium carbonate or sewage solids may carry the concentration further but at one plant using iron without lime the sludge removed contains only 1.6 per cent solids, and 45 per cent volatile matter. Both of these figures are much lower than on most plain sedimentation sludge.

An experimental plant, treating sewage with a solids content of about 150 p.p.m., removed 115 p.p.m. with a dosage of 270 lb. of ferric sulphate and 360 lb. of CaO per m.g. This treatment should result in a calculated dry solids recovery of 2330 lb. per m.g. The actual recovery was 1840 lb. per m.g. or about 79 per cent of the expected. Either

sewage constituents or chemicals react in some mysterious way to result in compounds with less weight, or CaO went out in the effluent in solution. Assuming the latter to have been the case, and reducing the $CaCO_3$ in the sludge to obtain the recorded figure for solids removed, it is found that the sewage solids contained 18,200 lb. and the chemicals 16,100 lb. of water. In this case the sludge contained 5 per cent solids. Further conditioning must have been necessary for filtration. In this case, coming away from the primary settlers, it was necessary to handle 88 per cent more solid material than in plain sedimentation. The same percentage relationship exists in dewatering and drying, unless acid conditioners are used to put precipitated chemicals back into solution.

In the report of observations made in another plant, the suspended sewage solids removed, if at 5 per cent solids, would have carried 58,400 lb. of water. The actual chemical precipitation sludge removed, if at 10 per cent solids, would have carried 77,400 lb. of water or 33 per cent more than would have been in the plain sedimentation sludge. The dry solids increased 182 per cent on account of chemical precipitation treatment. Results reported from another experimental plant show that the chemical precipitation sludge contained 16 per cent *less* water than the sewage sludge would have carried at 5 per cent solids, with an increase in dry solids to be handled of 77 per cent.

The results from the various plants, operating on a more or less full scale rate, and from experimental units, are quite confusing. Numerous advantages are claimed or suggested. Hyde and Hendon report that they believe that the laboratory determined B.O.D. of an effluent from a chemical precipitation plant affects the stream to a less degree than the same amount of B.O.D. in a plain sedimentation effluent. The opinions are unaccompanied by supporting data. A few years ago, in connection with the Indianapolis plain aeration plan of operation, the suggestion was made that such treatment might remove the most easily oxidizable organic matter, and thereby relieve the stream of the first rush of pollution. Extensive examinations showed that the organic matter, remaining after plain aeration, demanded oxygen at the same rate as that removed, so that the process had to its credit only the pounds of removal indicated by the laboratory examination. Unless chemicals act on dissolved organic matter to render it inert, or less easily attacked by bacteria, it is hard to understand why a chemical precipitation effluent will affect the free oxygen in a stream to a less extent than a like amount of organic matter from a biological plant.

Expression of Operation Cost

In a previous paper, the writer has urged the use of the cost of removing a thousand pounds of B.O.D. to express the efficiency of sewage treatment plant operation. The expression is not perfect since it does not take into account the completeness of treatment. It, however, has been found helpful at Indianapolis where changing methods

of operation (i.e., aeration without return of sludge) have caused the costs per million gallons to become distorted, showing a much more economical operation per million gallons with plain aeration than with sludge return.

At Indianapolis, when the plant extension now under construction is in service, the cost of removing 1000 lb. of B.O.D. will be $2.26 for operation and $4.23 for interest and depreciation, including such charges on the power plant which serves the activated sludge plant. This makes a total cost of $6.49 based on a full year's operation. If the diluting water available justified only summer operation of the final treatment process, the fixed charges would double, making the cost of removing 1000 lb. of B.O.D. $10.72 during the summer only. These costs for operation of the extended plant are based on figures obtaining for the ten years operation just passed. Using figures from three annual reports of one of the largest activated sludge plants, it is calculated that operation costs of the entire plant are at the rate of a little less than $5.00 per 1000 lb. of B.O.D. removed.

The Grand Rapids figures show that it is expected that chemical precipitation will remove 17 p.p.m. or 141 lb. per m.g. more B.O.D. than plain sedimentation at an added cost of $8.34 per m.g. for the summer only when the process is in use. The removal of 141 lb. of B.O.D. for $8.34 is at the rate of $59.15 per 1000 lb. which may be compared with the cost of $10.72 which is the summer only estimate for the biologic plant at Indianapolis.

Assuming that plain sedimentation would remove 40 per cent of the B.O.D. in the summer at the Shades Valley plant, it is calculated that chemical precipitation removed 327 lb. of B.O.D. per m.g. which cost $5.70 for chemicals alone. This is at the rate of $17.43 per 1000 lb. removed, without labor, supplies, or fixed charges.

In an article by Zack on sewage treatment, estimates are shown for two conditions of sewage flow and strength. The anticipated removals, cost of chemicals and entire plant cost are given. From these figures it is calculated that, in one case, 1000 lb. of removed B.O.D. will cost $16.14 and in the other case, $5.53 for chemicals alone, or $39.55 and $17.21, respectively, including operation and fixed charges. At Coney Island, the experimental work indicates a cost of $19.93, per 1000 lb. of B.O.D. removed, for chemicals alone.

At Dearborn, the chemicals are obtained at low prices. Calcium oxide cost $5.70 per ton and $FeCl_3$, 1.5c per pound. At these prices, and crediting the removals entirely to chemicals, the cost is $4.77 for chemicals alone, per 1000 lb. of B.O.D. removed. Using the customary prices of $12.00 per ton for lime and 2c per pound for ferric chloride, the unit costs increase to $6.86.

These few cost figures, based on accomplishment rather than volume of sewage handled, are picked at random from the literature and are sufficient to show that chemical treatment is expensive in its operation as compared with biologic plants, even including fixed charges, which are very much higher in the case of the biologic plants. Where some

relief is imperative and the bonding limit reached or money impossible to get for some other reason, the lower priced chemical plant offers a way out. Frequently available money forces one to purchase a lower priced machine even though it operates less economically.

General Considerations

It is conceded that chemical precipitation cannot, at present, meet the high removal performance of activated sludge. There are many places where sufficient dilution is available to absorb the organic matter in the sewage after chemical treatment. There can be no justification for the expenditure of a large sum of money to build a non-essential plant, especially when practically all of the chemical precipitation plant can be utilized in the complete treatment plant when stream loading demands it.

When a plant is operated in a seasonal fashion there are many months during which the plant must lie idle. Shutting down a chemical precipitation plant requires, only, that rather easily protected machinery be put into shape, since the main part of the plant will be functioning continuously. The labor in the chemical house can be replaced easily when again required and the laboratory kept busy on treatment problems until operation is resumed. In the writer's opinion it would be difficult to operate an activated sludge plant seasonally. Deterioration always occurs in an idle plant. Diffusers clog or freeze, pumps, valves, etc., require overhauling after standing. It is not easy to train a new force each year and green operators do not make for effective operation. This is not to be interpreted as meaning that a chemical plant is easier to operate than an activated sludge plant. It means only that labor to apply chemicals is easier to obtain and train than are activated sludge plant shift men. As a matter of fact, the chemical precipitation process requires as much or more technical supervision and attention in its operation as a biologic plant, and it probably causes as many headaches. Those who have operated water softening plants will bear witness to that statement. Chemical precipitation is just as sensitive as the activated sludge process and trouble can happen as quickly, but recovery may be realized much more rapidly. In a chemical precipitation plant, there is no long period of waiting to rebuild an active sludge.

Perhaps no chemical is so generally used or in such large quantity as chlorine. For the most part it is used as an aid in odor control and in preventing bacterial action which results in concrete deterioration. In some cases it has reduced B.O.D. appreciably. The failure of chlorine, used ahead of the activated sludge process, to make higher rates and more rapid biologic action possible, seems illogical despite the result of a number of experiments. Perhaps the methods of application have been wrong. Two experiments, using chlorine, are under way at Indianapolis, which it is hoped, may have an influence on the speed of biologic action. One reason for the success of chlorine in sewage treatment is that chlorine manufacturers, generally, have em-

ployed men to study its use scientifically instead of promoting it as a cure-all, as has been the case in connection with many other processes in the past.

A new product which may be classed with chemicals, is meeting with some success in sewage work. Activated carbon, found so very helpful in water purification, is reported as preventing scum formation on final settlers and promoting digestion of sludge. Its ultimate value will be determined with more experience in its use, and if its cost decreases greatly.

The flexibility of the chemical precipitation process is attractive. Advantage may be taken on short notice of unseasonably high water. A chemical precipitation plant may be converted into a plain sedimentation plant almost as simply as turning a valve or throwing a switch. As the water stage falls, chemicals may be added in gradually increasing amounts to meet the changing dilution demand.

As in the case of all other forms of sewage treatment, each situation requires study of the special conditions and demands. Sewages differ not only in their organic content but also in the nature and amount of dissolved salts. These latter are important in biologic processes but doubly so in chemical precipitation. Industrial wastes, varying as they do within the same industry, present major problems with their vastly changing compositions and volume. Chemical treatment methods have been found especially valuable in treating such wastes, either completely or in preparation for disposal through the municipal plant.

While the ferric salts have been found to be most effective in coagulating sewage solids, the choice of the particular chemical to use in a given plant is influenced by its location, freight rates and unusual sources of supply of other materials. Other things being equal, the purchase of chemicals all ready to apply is preferable to their partial or complete manufacture at the sewage plant, even at some slight increase in original cost. The sewage plant personnel has plenty to do without going into the chemical manufacturing business.

The ever present sewage plant problem is to produce an effluent which will meet the demand of the diluting water into which it must be discharged. This demand changes frequently. The successful plant operator takes advantage of all agencies at his command to meet this demand as economically as possible. As an important tool, chemical precipitation is here to stay, this time, and no doubt will be used sanely.

DISCUSSION OF PAPER BY A. J. BECK ON "DIFFUSER PLATE STUDIES"

By W. E. Howland

Asst. Prof. of San. Eng. Purdue Univ., Lafayette, Ind.

The studies reported by Mr. Beck (This Journal, 8, 22, Jan., 1936) have proved conclusively that the air bubbles emitted from coarse diffuser plates are not greatly larger than those emitted from fine plates. The uncertainty in the minds of designers on this point has hitherto stood in the way of a wise choice of porosity of plate for particular installations. Mr. Beck's studies have also thrown a great deal of light on other important details of the behavior of diffuser plates.

Tests on Lifting Effect

In this discussion the writer will first present an unpublished study of his own on the "Lifting Effect of Air Bubbles from Plates of Various Porosities" which early led him to the conclusion mentioned above. These experiments were so different from those of Mr. Beck as to constitute a sort of independent check, or at any rate to lend confirmation to results of his work.

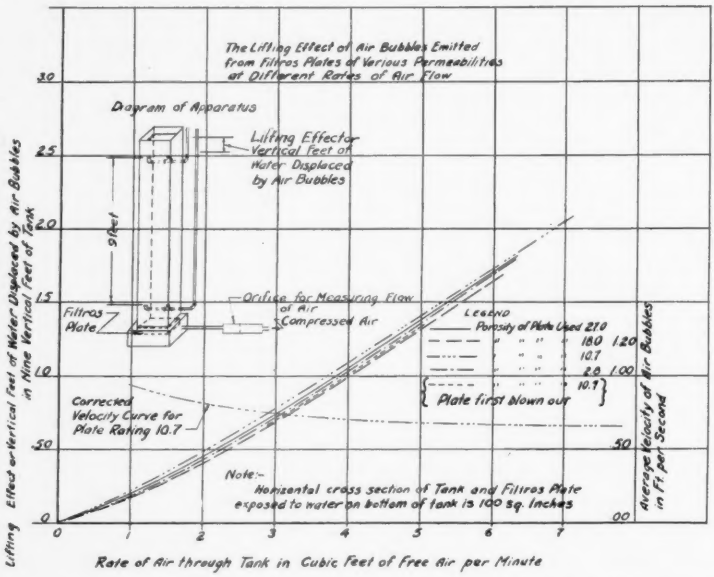
As shown in the accompanying diagram, a vertical tank of about 10 ft. depth and 100 sq. in. in horizontal cross section was constructed and equipped with a so-called plate box in which various plates could be placed so as to admit air at measured rates to the bottom of the liquid contents of the tank. Two open glass piezometers were inserted into the side of the tank to permit the measurement of the instantaneous amount of air entrained in the 9 ft. portion of the tank located between the two pairs of inside, upwardly directed, openings of the two piezometers. The difference in the water surfaces of the two piezometers was a direct measure of this instantaneously entrained air and was called the lifting effect.

As shown by the curves the lifting effect increased with increased rates of flow but was almost independent of the porosity of the plate from which the bubbles were emitted. In other words it appeared from these tests that porosity of plate had practically no effect on the behavior of the bubbles. This in itself was thought to be a very strong reason for supposing that coarse plates would give good results in an activated sludge tank for it was supposed that this lifting effect determined the mixing effect and that good mixing was the main concern of the designer—there being much more than sufficient air to maintain 100 per cent saturation of dissolved oxygen.

The curve sheet shows also the computed velocities for one series of tests. The velocity is, of course, directly proportional to the rate of flow of air (at average pressure conditions in the tank) and inversely related to the volume of instantaneous entrained air in the tank. (If the flow-lifting effect curves were straight lines then the velocity curves

would be horizontal lines. The decrease in the velocity at higher curves indicates, probably, the effect of mutual interference of bubbles.)

According to this reasoning, equal lifting effects at equal flows would indicate equal velocities of bubbles for the different plates under these conditions. It was supposed that the larger the bubble the higher its vertical velocity. The fact that the bubbles of different plates seem to have the same velocity indicated, then, an approximate equivalence of size.


The Lifting Effect of Air Bubbles Emitted from Filtros Plates of Various Permeabilities at Different Rates of Air Flow
Diagram of Apparatus
Lifting Effect or Vertical Feet of Water Displaced by Air Bubbles
9 Feet
Filtros Plate
Orifice for Measuring Flow of Air
Compressed Air
Legend
Porosity of Plate Used 21.0
" " " " 18.0 12.0
" " " " 10.7
" " " " 2.8 1.00
" " " " 10.7
Plate first blown out
Corrected Velocity Curve for Plate Rating 10.7
Note:- Horizontal cross section of Tank and Filtros Plate exposed to water on bottom of tank is 100 sq. Inches
Lifting Effect or Vertical Feet of Water Displaced by Air Bubbles in Nine Vertical Feet of Tank
Average Velocity of Air Bubbles in Ft. per Second
Rate of Air through Tank in Cubic Feet of Free Air per Minute

These tests were performed with the cordial and helpful assistance of the General Filtration Company at East Rochester, New York, while the writer was there as inspecting engineer for the Chicago Sanitary District. (The apparatus was constructed wholly at the expense of this company.) He submitted his findings to his office in the spring of 1925.

Photographic Determination of Bubble Size

In the spring of 1931, R. R. Steinmetz, working on a thesis for the Bachelor's degree at Purdue University under the direction of the writer, studied photographically the size of bubble emitted from ¾ in. diameter plugs formed from Filtros plates of different porosities. These plugs were kindly furnished by Mr. W. R. Beckley of the General Filtration Company. The pictures obtained showed bubbles of distinct size but the variation of size of bubbles on a given plate appeared to be large (a result since confirmed by Mr. Beck) and although it appeared that the different plugs gave bubbles of approximately equal average size the results could not be claimed to be statistically significant. What was needed was large photographic plates showing more bubbles.

The writer's experience with this photographic method makes him aware of the many difficulties and therefore very appreciative of the very excellent pictures and definite results obtained by Mr. Beck.

Rating of Diffuser Plates

I wish to emphasize the importance of the master plates as a device for avoiding errors in rating. This practice was uniformly used by me as inspector and rater of plates in Rochester. Ratings of five master plates, on 47 days scattered quite uniformly throughout the period from October 23, 1924 to March 10, 1925, ranged from 16.7 on one day to 15.3 on another, with an overall average of about 16.2. I did not apply temperature or barometric corrections but on the other hand I did not rate plates for acceptance on days when the master plates showed abnormal ratings.

On one series of days when these plates rated low I noticed that the weather was rainy and also recorded that the temperature and pressure variations from standard were not sufficient to cause the trouble. Although Mr. Beck's tests indicate that a certain wide range of humidity does not affect the plate rating it is my opinion from my experience that wider variations may do so, not merely because of changes in viscosity as Mr. Beck suggests but also perhaps because of absorption of water vapor in the pores of the plate.

Causes of High Losses in Used Plates

As mentioned by Mr. Beck, the writer in 1924 continued the work of S. I. Zack and R. J. Bushee on the magnitude of losses in used plates and the effectiveness of certain means of reducing these losses. Certain unpublished suggestions and conclusions from the writer's earlier report, which now receive additional confirmation from Mr. Beck's own studies, should receive additional emphasis.

Mr. Beck has found that the clogging of plates is high when the concentration of sewage above the plate is high as in the case of sludge reaeration tanks and this clogging is lessened by continuous blowing out of air at a high rate in clean water or sewage of low concentration. Both of these effects were noted in the earlier studies and led to the suggestion that one important cause of high losses of pressure through the plate might be the filtering down into the pores of the plate of sewage solids. Mr. Beck's finding that the clogging takes place in the top ⅛th inch of plate tends to confirm this view. Is it not likely that the occasional reduction in pressure in the air lines due to shutting off of the blowers is responsible for the filtering down of the sewage as was suggested in the earlier report? If this view is not contradicted by other findings not known to the writer then it would seem to be wise to explore this hypothesis further and possibly even consider means of maintaining a constant pressure under the plate so as to avoid such filtering by the automatic admission of clear water into the air passages under the plates through plate box drains or otherwise, whenever the air might be shut off.

Further, the occasional blowing out of plate boxes at a high rate with depressed sewage levels and without the return of activated sludge in the tank would appear to be good practice for the maintenance of low losses in the plates. The writer found that the apparent cleaning of the plate which immediately followed the high rates of air flow was largely lost in subsequent operation of the plate, apparently because a good deal of the cleaning effect was due to the blowing out of the water from the smaller passages and this water returned due to capillary action at lower rates of air flow. But if Mr. Beck's explanation for such cleaning as he found is a good one,—namely that the bacteria actually consumed the organic material in the plate under these conditions, then the occasional cleaning of the plate in this way would appear to be beneficial.

Mr. Beck: *Lifting Effect.*—The tests on lifting effect show how much air is dispersed throughout the liquid. However, the test does not indicate the size of the bubbles because the volume of air entrained varies with the air rates, but not with the bubble size.

Experimenting with a 4-inch pipe 15 feet long, with a glass section at the bottom and at the top, it was found that 21 seconds was required for the bubbles to rise and no difference could be noticed in the rate of rise between the large bubbles and the small bubbles given off by a diffuser plate.

Causes of High Losses.—The rapid clogging of the sludge reaeration tank at the North Side Treatment Works could not have been due entirely to sludge filtering into the plates, because 35 other aeration tanks were on the same air main and none of these plates clogged. Undoubtedly, most of the clogging in diffuser plates ordinarily is due to sludge filtering into the pores.

The use of exceedingly high air rates for 24 hours on the diffusers at the North Side plant caused no reduction in pressure loss.

Industrial Wastes

PROGRESS IN MILK WASTE DISPOSAL *

By C. R. Roberts

Sheffield Farms Co., Inc., New York City

The milk plants in the so-called New York milkshed may be divided into three general groups, basing the classification upon the types and amounts of wastes produced.

First, the shipping station receives milk daily from 50 to 200 dairymen. The plant in this class may handle from 12,000 to 70,000 lb. of fluid milk daily. The milk, when received, is dumped, weighed and sampled. The milk cans are then washed and the milk, after cooling, is drawn off into 40-qt. cans, or more generally pumped into a tank truck or car for shipment to the city. The milk wastes from these stations consist of fluid milk that comes from spillage, can rinsings and equipment rinsings, in conjunction with washing compounds.

The second group can be called semi-manufacturing plants, in view of the fact that the fluid milk after being received from the farmers, is

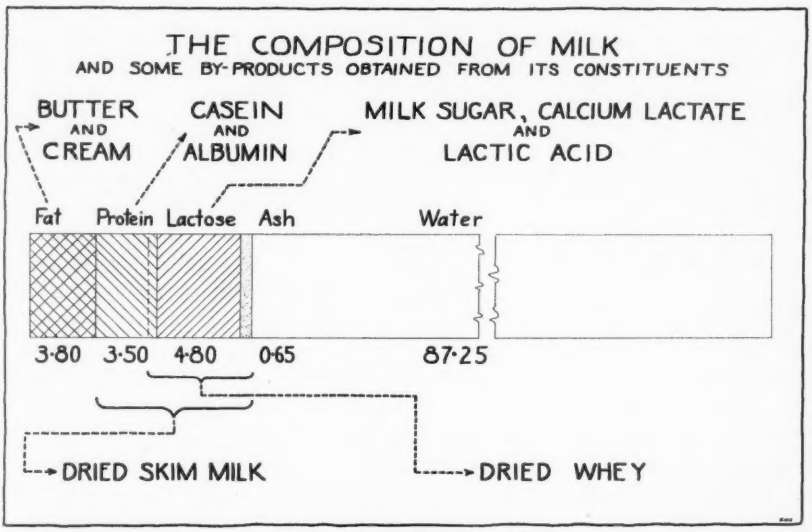


FIG. 1.—Composition of milk.

only partly manufactured. The daily receipts vary from 40,000 to 170,000 lb. of fluid milk. The milk is passed through separators and the cream shipped to the city. The skim milk is generally manufactured into casein. In this class we also find the cheese plant that is very common in the northern part of New York State, where whole milk

* Presented at the Eighth Annual Meeting of the New York State Sewage Works Association, New York City, January 14–17, 1936.

is manufactured into cheddar cheese. There is also the butter operation, so prevalent in the past, but which has recently moved to the midwest area of the United States. In addition to regular shipping station wastes, whey wastes are discharged from the casein, cheese or butter operations. These wastes consist of some butterfat, milk sugar, some protein, as well as the salts normally present in milk (Fig. 1).

The third group may be called complete manufacturing operations. In this class the plant handles up to 325,000 lb. of fluid milk daily. Here the same procedure may be carried on as in Group 2, but in addition to the removal of fat and protein, other solids are removed, so that more complete recovery is obtained in this type of plant than in the second group.

Production and Disposal of Wastes

The ordinary shipping station operates over a period of only four to five hours, therefore the wastes are discharged during this period. Progress has been made in cutting down the amount of these wastes. Several years ago our company realized that we were not making the progress in this type of plant that we should and consequently we proceeded to modernize the operation. First, the dumping of the farmers' milk into the weigh can was a rather wasteful operation, and no matter how conscientious the operator, he was bound to leave approximately ½-pt. of fluid milk in each can. This meant that with a 400-can plant, approximately 100 quarts of milk, with all of its fat and solids, was going down the sewer daily. In addition to this, even with the best of operators another 100 quarts was spilled in the receiving process. Also in cooling milk through a series of tubes, commonly called an IT cooler, it was impossible to force all of the milk out of the tubes at the end of the operation. This meant that another 15 quarts was added to the waste. In modernizing these plants, the first problem to overcome in the loss at the weigh can meant the expenditure of several thousand dollars, with automatic dumping arrangements so that the milk cans could be emptied completely, thus overcoming the spillage. Objections were raised by municipal boards of health to inversion of the cans directly over the weigh can. To obviate this difficulty, extensive washing and drying equipment had to be installed in order to wash and dry the can on the outside before it reached the weighing device. However, all of these obstacles were overcome; with this modern type of operation the amount of fluid milk lost at the weigh can has now been cut down so that very little goes down the sewer. Next, to reduce the amount of milk left in the cooling equipment, an air compressor was installed and the last bit of milk was forced out into the tank car or truck by filtered air. This means that the amount left in the cooling equipment has now been reduced to 4 quarts. These changes, together with other minor corrections to prevent milk leaks in the shipping station plant, resulted in at least 50 per cent reduction of wastes. In view of the preliminary rinsing and drying given the cans before reaching the weigh can, the amount of washing compound required in the can washer has also been reduced.

Such material as straw and dirt clinging to the exterior of the cans from the farmers' trucks has been eliminated before reaching the weighing device, resulting in use of less washing compound to give a clean can.

During the past year our company alone installed eight of these operations at a cost of approximately $50,000 and we expect to continue as fast as it is practical to do so.

At present the milk draining from the can before it is washed is not saved or utilized because of Health Department rules. We expect, however, to work on this problem, and if we have success, the amount of waste will have been brought down about 50 per cent again.

Although most of the shipping stations discharge waste during a period of 4 to 5 hours, considerable improvement can be obtained in many cases by having this discharge distributed uniformly over a 24-hour period.

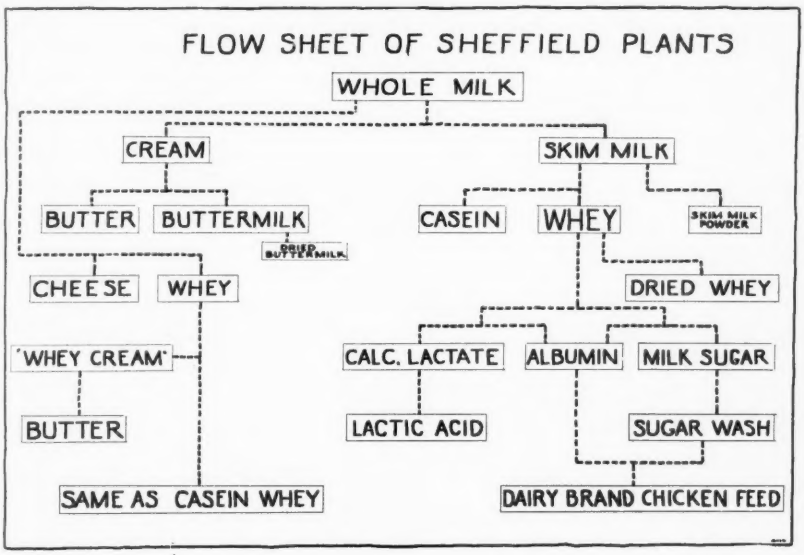


FIG. 2.—Flow sheet of milk products.

In the group comprising semi-manufacturing operations, improvement has also been made, resulting in reduction of milk wastes (Fig. 2). In the cheese operations of the past, all whey was discharged into streams without any thought of recovery of solids. This meant that valuable butter fat was lost, as well as other solids. Consequently, separators have now been installed in all cheese plants so that the whey can be separated and the butter-fat removed for manufacture into whey butter.

Considerable study is being given to the recovery of other solids in cheese whey. Last summer attempts were made to boil the whey and thus precipitate the solids, but apparently this type of handling will

not recover sufficient of the protein to be practical. Another season more complete recovery is expected by use of lime in conjunction with boiling.

Another plan under experimentation is the use of a special hot roll drier, which if successful, can be used to dry the cheese whey and recover the solids.

In the manufacture of cream into butter, the waste from the operation consists of buttermilk and butter wash water. These two products contain from 1.5 to 8.5 per cent solids. These wastes were handled as follows at one of our butter plants last summer:

The buttermilk from the butter operation was dried on a hot roll, and made into dried buttermilk for poultry feeding; the butter wash was discharged into the sewerage system and filtered through sand beds. Such an excessive milk scum growth was produced that the sand beds clogged in a short period of time.

This wash water was consequently removed from the sewer and pumped into tanks with the casein wash water. It was there treated with HCl, and the curd was removed by boiling, thus combining with the albumen and making a very satisfactory chicken feed.

With the removal of this material, the beds immediately cleared up, and the problem, to a large extent, was overcome.

In this connection, it might be worth while to mention that in 1934 this plant recovered 638,000 lb. of poultry feed, while in 1933, only 220,000 lb. was recovered. The plant handled the same amount of skim milk both years, so that the increase was due to better recovery from the wastes.

In the third group, or the type we have called complete manufacturing operations, lies a field that we feel has a very bright future. As a result of this feeling, our company for the past few years has been experimenting considerably at Hobart, New York, with the idea of developing products and markets for these products, so as to recover all solids.

After removal of the cream, the skim milk is pumped to the casein machine, where the casein is precipitated by adding dilute acid. The water used to wash this casein picks up considerable protein and also has to be treated to remove protein deposits. From here the residue runs into tanks where albumen is precipitated. The whey next goes to evaporating pans and the milk sugar is crystallized. This crude sugar is then washed, the wash water recirculated, and the sugar again crystallized. In this procedure considerable of the salts in milk are combined with the sugar and the final residue is made into poultry feed.

As a result of these processes, most of the solids are removed, so that the sewage contains only floor rinsings, with some salts.

It appears from this description that the problem is rather simple, but it must be considered that the markets for some of these products, especially milk sugar, is very limited, and therefore it is impractical to turn all manufacturing operations into these products.

A product has been developed called 'calcium lactate,' which is used

in pharmaceutical preparations. This calcium lactate can also be made into lactic acid, and is used in ice cream sherbets, preserving of pickles, olive packing, and in certain tanning processes.

Another product utilizing the lactose in milk is sodium lactate, which can be used for anti-freeze solutions and has proven valuable in the printing of colored fabrics.

Although with these complete manufacturing operations practically all solids are utilized, considerable money must be expended in the form of buildings and machinery in order to recover all of these products and the program of extension, therefore, is bound to be a slow one. At Norwich, N. Y., our company at the present time is erecting a plant which, will cost upwards of a quarter of a million dollars, to recover these products so that we will be in a position this spring to turn out a waste that should not be objectionable, even at the height of the flush milk season. Without a doubt, other installations will be made from time to time, if market conditions for the products remain satisfactory.

Treatment of Wastes

At present we have three trickling filters successfully treating milk wastes at country plants. At one of these plants, a few years ago, the wastes were a great problem. The plant is located in a lowland section, a few miles from the St. Lawrence River. There are no streams of any volume nearby and the milk wastes, discharged into an open ditch, were creating a nuisance. As a result of this condition, a trickling filter was installed, with the aid of valuable information from the engineers of the Sanitation Department of the New York State Department of Health.

This trickling filter was constructed about 500 ft. from the milk plant. The filter has a diameter of 43 ft. at the top, 47 ft. at the bottom, and is 10 ft. deep. The waste from the plant flows to a surge tank with a capacity of 14,000 gallons. Here a sump pump works automatically, forcing the sewage through the Dorr rotating distributor over the filter. The filtered waste runs by gravity to the secondary settling tank and from there to an open ditch.

The milk plant handles between 81,000 and 85,000 lb. of fluid milk daily. The milk is separated into cream and the skim milk dried by the spray process into milk powder. The solids content of the waste averages about 0.1 per cent.

The effectiveness of this filter has been checked on two occasions by representatives of the N. Y. State Department of Health.

At the time of the inspection, the ditch into which the waste is discharged was dry above the entrance of the effluent and had been so for about four weeks. Only about 2 sq. ft. of the filter appeared to be partically clogged by fine material and all water disappeared from the surface during the interval between dosing. The effluent from the filter immediately after dosing was quite turbid but the latter flow was clearer. A sample taken at the outlet of the secondary tank at the

height of the milk waste operation was found to contain 3.2 p.p.m. dissolved oxygen. No odor was noted along the bank of the ditch at any point, although the entire flow was treated waste.

About 500 ft. below the entrance of the effluent, the dissolved oxygen content was found to be 6.4 p.p.m. Samples taken at various points for methylene blue determination were checked and it was found that a distinct blue was maintained for about 2 days with 25 and 50 per cent dilutions.

I believe that sufficient data have been gathered at various plants throughout the United States to warrant the statement that the trickling filter is one of the most satisfactory ways to treat milk wastes.

There are many possibilities in treating milk wastes that may be developed, and I might mention one process that is being studied by the Research Laboratories of National Dairy Products Corporation at Baltimore. The procedure consists of de-lactosing the wastes by yeast fermentation, with recovery of alcohol and a lact-albumin yeast precipitate. This precipitate may be used for feeding purposes either in a dry or semi-solid form and the alcohol used for commercial purposes.

In many instances sewage disposal plants located throughout New York State are built with settling tanks followed by trickling filters. In some cases, wastes from a milk plant gum up the works, so to speak, of the village disposal plant, when the sewage and wastes enter the settling tanks. In these instances, I wonder if improvement can be obtained by by-passing the milk wastes around the settling tanks, directly to the trickling filter. As a result of this mixture, the pH of the milk wastes would remain more on the alkaline side, and from what we know of trickling filters, it would seem as if this milk waste sewage mixture could be treated satisfactorily by the filter. I am simply throwing this out as a suggestion which may or may not have any merit, but if it could be done effectively, it certainly would be an aid to the milk industry.

From what I have stated, I believe you can rightfully draw the conclusion that we in the milk industry are more interested in developing ways to recover valuable material from milk wastes than to treat them by processes of sewage treatment.

Discussion

By Professor C. L. Walker, *Cornell University, Ithaca, N. Y.*

Experience in dealing with the problems incident to the disposal of industrial wastes suggests three procedures for the solution of such problems—

(*a*) Elimination of the problem by elimination of the waste.
(*b*) Improvement in the performance of units used in prevailing method of treatment in use.
(*c*) Development of new methods.

While there is some overlapping in these procedures, they represent fairly distinct objectives. New and previously unknown procedures

are not frequently advanced and it is therefore natural that Dr. Roberts' paper points out progress that has been made in the recovery and utilization of the waste, and in improving the performance of existing types of treatment units found best adapted to treating the wastes.

It has been pointed out that it is not primarily the volume of waste but the pounds of milk solids in the waste that should be the concern of the industry and of the engineer designing a treatment plant. Methods of operation which reduce the loss of whole or skim milk will apply to all plants, large and small, and are of great benefit to the industry.

The Sheffield Company is to be commended for the efforts made to improve conditions by preventing waste of raw product.

Recovery Processes.—During the summers of 1920 and 1921 at North Lansing and Caroline, New York, respectively, an attempt was made to remove nitrogenous elements from whey by boiling with lime. A heavy curd, which was dried with difficulty, was obtained. As a fresh food it was quickly consumed by neighborhood chickens. The best results obtained in a limited number of tests indicated that from 75 to 95 per cent of the organic nitrogen and 25 per cent of the total solids of the whey could be removed by the process. Eleven pounds of curd were produced per 100 gallons of whey. The effluent of the boiling process appeared turbid, was practically sterile, and devoid of oxygen. When applied to sand beds, after storing and cooling, the beds soon flooded. The results of further experimentation with this method during the coming season will be awaited with much interest. The results obtained during the seasons of 1920 and 1921 were published in a bulletin prepared under the supervision of a committee of the Agricultural Experiment Station of Cornell University, and numbered 425.

Drying wastes on a hot roll has been tried with success. Commercially, however, difficulties have been met. Unless given some previous treatment a waste containing 5 per cent of lactose when partly dried is very viscous and is removed from the hot roll with much difficulty. In work done at the Wolcott plant of the Sodus Cooperative Creamery Company by the Buffalo Forge Company, bran and corn meal were added to the whey prior to running it into the pan under the drying roll. This gave a mat which could readily be scraped from the hot roll. Difficulty was experienced in marketing the resulting feed produced at more than the prevailing prices paid for the bran and corn meal.

The operation of a drying roll, or the boiling of whey, will add to the labor, power, and overhead charges at the plant, making it necessary to increase the cost of the manufactured product or to reduce the earnings of the plant. This would be of considerable importance in the many small plants which exist.

Aerobic Treatment.—It has been repeatedly shown during the past few years that aerobic rather than anaerobic methods of treating milk wastes are more efficient in preventing nuisance. Particularly notable are the contributions of Levine, Burke, Linton, Soppeland, Watkins, Galligan and Goresline at Iowa State College; the work of Eldridge at

the Michigan State College of Agriculture and Applied Science; the findings of Ruf and Warrick in Wisconsin; and the confirmatory evidence obtained by Kimberly in Ohio.

The encouraging results obtained at one of the three sprinkling filters recently built by the Sheffield Company argue for the contribution of additional filters where feasible. Filters can be designed for large or small plants, and the supervision of such filters does not require constant and exacting supervision. It would be of interest to know to what extent changes are produced in the waste applied to these filters and how these changes are affected by temperature, by the frequency of dosing, by the rate of operation and by the strength of the waste applied.

A wealth of information is available in the bulletins and articles prepared by those mentioned above, and in part referred to in the bibliography appended.

The studies that have been made indicate that best results with sprinkling filters are obtained:

(*a*) When cinders or stone from 1½ to 3 in. are used as the filter material.

(*b*) When the depth of the filters is from 5 to 9 ft. with a depth of 6 to 8 ft. most common.

(*c*) With waste applied at rates varying from 500,000 to 1,000,000 gal. per acre per day over a period of ten to fourteen hours. Kimberly in the Ohio work tentatively suggests 80 cu. ft. of filter space per pound of milk solids to be treated daily.

(*d*) With the waste is applied frequently in small doses rather than less frequently and in larger doses, the reduction in B.O.D. seemingly varies inversely with the duration of dosing cycle, and is greater for a dosing cycle of 7 minutes than for one of 20 to 25 minutes. Levine found that a raw waste of 1100 p.p.m. B.O.D. when applied at varying lengths of dosing cycle to a filter 6 ft. deep at the rate of 800,000 gal. per acre per day, would be modified as follows:

For a 7½ minute cycle, B.O.D. of the effluent was 95 p.p.m.
For a 10 minute cycle, B.O.D. of the effluent was 128 p.p.m.
For a 20 minute cycle, B.O.D. of the effluent was 229 p.p.m.

(*e*) With filters constructed so as to be ventilated at the bottom and allowing for circulation of air through the filter.

Use of Chlorine in Irrigation.—In arid regions, where the irrigation of soil is necessary, milk wastes have been applied as an irrigant, sufficient chlorine being added to prevent the development of objectionable odors before the waste is absorbed by the soil. This process has been used at Phoenix, Arizona, and at Wasco and Tulare, California.

Combined Milk Waste and Sewage Treatment.—When the combined waste does not have a B.O.D. greater than 1000 to 1200 p.p.m., experimental results indicate that trickling filters can be used to treat the combined waste, provided the milk waste has not been in transit so long that the lactose has undergone decomposition, with the attendant

objectionable acid reactions. Eldridge and Zimmer conclude that, "Primary settling may be accomplished satisfactorily if the detention period plus the time required for the milk waste to reach the plant does not exceed 2½ to 3 hours," a short period of time. Where the milk wastes are too concentrated to be introduced to the sewer directly, partial treatment at the factory and final treatment at the sewage plant is a possible solution, and one involving less expense and trouble than complete treatment at the plant.

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BY L. I. HOLDREDGE

District Sanitary Engineer, Oneonta, N. Y.

As engineers, we are so much concerned with the mechanics of waste disposal that we often overlook the fact that some of the materials we think must be handled in treatment plants may have a real commercial value, waiting only for someone to recognize the fact and develop a market.

Many of us have found to our sorrow that it requires but a very small quantity of lactose to raise havoc with the orderly operation of settling basins and septic tanks. The chief reason for this is the fact that lactose is very readily oxidized to lactic acid, which quickly inhibits the growth of most of the anaerobic bacterial species so helpful in reducing the volume of precipitated solids. When the oxidation of lactose has been allowed to proceed to a point where a value of 4 or 5 on the pH scale is indicated, the action of most microörganisms is almost completely inhibited. Some of us have tried to correct this condition by the addition of lime or caustic soda, only to find that calcium or sodium lactate is almost as toxic to our friendly anaerobic bacteria as is the free acid.

There are perhaps few of us who realized, until Dr. Roberts mentioned it, that this same calcium lactate has a definite market value as such and that the corresponding sodium salt has many of the properties of glycerine and in fact can be used as a substitute in the cotton print industry, and even as a substitute for "Prestone," which itself is a product closely related to alcohol and glycerine.

In order to prevent this effect of lactic acid in our wastes, it is necessary to carry oxidation to completion, so that there is left only CO_2 and H_2O. The sprinkling filter, fortunately, affords a very satisfactory means of such oxidation, as has been so well proven by the work of Levine in Iowa, Warrick in Wisconsin, and others working in the northern part of that great middlewestern section of our country where milk goes more generally into manufactured products and consequently milk waste is a more important problem than in the east.

These investigators have used filters of crushed stone, in most respects comparable to the standard trickling filters used for sewage treatment. With such beds, working on the basis of intermittent dosing, it has been possible to handle from 2,000,000 to 3,000,000 gal. of waste per day, per acre of filter surface. Measured with reference to the "strength" of the waste or of its oxygen consuming power, about 90 cu. ft. of crushed stone was required per pound of 5 day B.O.D.

From the very beginning it was recognized that proper dissemination of oxygen through the bed was an important factor and we find Levine studying the effect of under ventilation and Warrick designing filters entirely above ground, with the stone held in place only by an iron frame work thus affording access of air on all sides.

Actual work among the investigators of any problem is always one or two years ahead of anything they are able to publish in bulletins or papers. Halvorson, working in Minnesota, has to date published very few of his results. He has apparently extended the idea of a plentiful air supply for the interior of the filter, by furnishing it with forced underneath ventilation. He has improved the distribution of the liquid over the surface by substituting tile for cracked stone and has employed the principle of recirculation so successful in activated sludge plants.

Coming now to the work at Hobart, New York, with which I have been most immediately concerned, it was early shown that more than half the total volume of waste could be eliminated from the village sewerage system by discharging all cooling and condenser water from the plant directly into the river. As for the remainder, the casein was precipitated with dilute hydrochloric acid, the milk sugar removed by crystallization from concentrated solutions, and the lact-albumin by neutralizing with lime and heating nearly to boiling. This left only the casein wash water from which it was impractical to recover the last traces (about 0.5 per cent) of milk sugar, which nevertheless was sufficient to cause much trouble.

There has now been developed a market for milk salts, for in them is contained vitamin G, which has claimed attention as being in some way intimately connected with the reproductive function. It is planned now to condense all casein wash water for the recovery of these salts, at a profit.

Whether or not this will prove a convenient source for this important vitamin, it certainly appears that the time is at hand when, at least as far as the milk by-product recovery plants are concerned, it will pay in dollars and cents to keep the waste out of our streams and sewage disposal plants.

Editorial

USE AND ABUSE OF THE B.O.D. TEST

The value of the B.O.D. test in sewage analysis is now almost universally acknowledged, but analysts who expect it to have the precision of a purely chemical determination, such as the Kjeldahl method for organic nitrogen, are bound to be disappointed. It is actually rather remarkable that the test has reached whatever precision it may now have, in view of the fact that it is a biological procedure, based on the growth of bacteria, and limited by the solubility of atmospheric oxygen in water. Condemnation of the test is usually due to lack of skill and care in its technique, expectation of impossible accuracy in results, or failure to make allowance for the vagaries of bacterial growth. Experienced investigators are sometimes disheartened by enormous variations in check results, but these occasional anomalies are bound to occur and usually the reason for such anomalies can be found. The paramount value of the test warrants the occasional inclusion of inconsistent results.

The limitations of the dilution method are well known, namely, the limited solubility of atmospheric oxygen, and consequent high dilution factors; the difficulty of obtaining a reproducible, zero-demand dilution water; the problem of seeding sterile or bactericidal liquors; and the "marginal" errors due to too high or too low depletions. These limitations have led to the several "direct" methods of determination, based on measurement of volume of oxygen absorbed, but these methods are cumbersome, somewhat artificial, and sensitive to the presence of bactericides which lose their toxicity when diluted. An exception to this indictment of direct methods may be due the "Odeeometer," in which the advantage of immediate and easy estimation of oxygen absorption may outweigh the disadvantages just mentioned. However, further research is needed to determine the value of this ingenious tool in the kit of the sewage works chemist.

One of the most interesting studies of oxygen demands and other measures of sewage strength is that reported by Messrs. Lovett and Garner of the West Riding of Yorkshire Rivers Board, abstracted in THIS JOURNAL, March, 1936, page 338. The authors are a little disappointed in the correlation of B.O.D. and other determinations such as oxygen absorbed from permanganate or dichromate, organic carbon, etc., and they conclude that some better test than the B.O.D. is desirable, but they do not propose any substitute. They devised an improvement of the Sierp apparatus, providing for a constant pressure adjustment. Inspection of the curves they obtained over extended periods of incubation indicate that possibly the apparatus may have leaked, and if so, the longtime demand might have continued forever.

Dr. Bach in Germany is also doubtful about the B.O.D. test. He refers to the large dilution factor and the vagaries of the micro-flora and micro-fauna; the undesirable use of oxygen and production of unabsorbed gas in the direct method; and the long time required to obtain results. In a letter to the writer, Dr. Bach states that he objects to the present B.O.D. methods, not with the idea that the test should be abandoned, but that it needs further improvement before it can be adopted universally. If this viewpoint is sound, it is inconsistent to use the oxygen consumed test so universally popular in England and Germany,

because this proximate determination is almost as variable and indefinite as the B.O.D. test. The only redeeming feature of the permanganate and dichromate tests is the rapidity with which the determination can be made. It is high time such tests were abandoned and the determination of organic carbon adopted.

Returning to the dilution method, the question of dilution water continually recurs. Lea and Nicholls have reported results of extensive research on synthetic water in this issue (pages 435 to 447). The conclusions may deserve rather critical study because the authors propose the use of a synthetic water containing a relatively enormous amount of nitrogen, when one considers the dilution factor of 120. The ammonium sulphate used (2.66 p.p.m.) has an oxygen equivalent of about 2.5 p.p.m. if oxidized to nitrate, which with a dilution factor of 120 would account for a B.O.D. of about 300 p.p.m. Although Lea and Nichols could find very little nitrite or nitrate and concluded that the ammonia was used "solely as a body building material by the bacteria in their growth," it seems to the writer to be unwise to recommend the use of so much nitrogen in a synthetic water.

Another interesting study is reported by Dr. Heukelekian (pages 415 to 421). He found somewhat higher bacterial counts and higher B.O.D. results with increasing concentrations of dissolved oxygen. This conclusion contradicts the assumption that B.O.D. is independent of the range of dissolved oxygen in the dilution bottles, a fundamental axiom of the dilution method. Further work along the lines of Dr. Heukelekian's research is therefore desirable. Some anomalous results appear in his tables and his conclusion that there are two optimal ranges of concentrations, at 2.0 to 3.5 and 12 to 18 p.p.m. dissolved oxygen, seems to be a little illogical and subject to further proof. Nevertheless, his work raises an important question in further development of the dilution method for B.O.D.

These comments on quite recent research and discussion emphasize only some of the difficulties in the path of improvement of the B.O.D. test. The problem of seeding is probably more difficult and the procedure is less standardized than some of the other phases of the B.O.D. test, but only a beginning has been made on this subject. The work of Butterfield and Purdy is the foundation for further work on seeding.

Notwithstanding the deficiencies of the technique of the B.O.D. determination, it still remains one of the most valuable tests for determining the strength of sewage, the efficiency of treatment, the disposal of effluents in streams, and the strength and influence of industrial wastes. Critical disparagement of the test is desirable, in order to call attention to the interesting research problems inherent in its further development.

F. W. MOHLMAN

Proceedings of Local Associations

MICHIGAN SEWAGE WORKS ASSOCIATION

Eleventh Annual Meeting

East Lansing, March 30 to April 3, 1936

The Eleventh Annual Meeting of the Michigan Sewage Works Association was held at Michigan State College, East Lansing, Michigan, March 30 to April 3, 1936, inclusive. The first three days of the conference were devoted to the annual short course school conducted through the courtesy of Michigan State College by members of its faculty. In addition to the three courses given in previous years, a course devoted to the practical phases of plant operation was included. This is the first year that this work has been given and it was presented somewhat in the nature of an experiment. However, it proved to be very popular. The conference and school was attended by 98 plant operators and persons interested in sewage treatment work.

The paper by Mr. N. G. Damoose, Superintendent of the Battle Creek Sewage Treatment Works, on the "Chemical Precipitation Studies at Grand Rapids" was exceedingly instructive and presented the possibility of the use of chemical precipitation in conjunction with existing methods.

E. D. Rich, Director of the Bureau of Engineering, Michigan Department of Health, discussed interesting factors of the new plants which are under consrtuction or have recently been completed in Michigan. A review of this paper was particularly interesting in comparing the new methods of sewage treatment as contrasted with those in use years ago.

E. F. Eldridge, Research Assistant of the Engineering Experimental Station of Michigan State College, spoke on the treatment of trade wastes, particularly confining his remarks to the treatment of sugar beet wastes. Besides the particular problems involved in the treatment of these wastes this paper indicated to the audience the possibility of extending its field of activity into the treatment of wastes of the various industries. The amount of pollution from such sources and the difficulty and complexity of their problems presents a challenge to the field of sewage and waste treatment.

S. L. Tolman of the Sanitary Engineering Division of the Jeffrey Manufacturing Company presented a most excellent paper on the effect of ground garbage on sewage and the treatment plant, referring particularly to the experiences at Indianapolis where the garbage of the city was ground and discharged into the city sewers for several months.

Experiences encountered in operating the municipal disposal plant at Charlevoix were discussed by Vincent Madison, Superintendent of

Municipal Utilities. This plant is of particular interest because of the critical location and the attention given by the designing engineers, Greeley and Hansen, to the problem of odor control.

E. C. Schneider, City Engineer, Fremont, described the rebuilding of the treatment plant at Fremont. This is a particularly interesting development because of the prevalence of a large amount of canning factory waste which is treated at the plant along with the municipal sewage. The old plant was constructed about 1921 and has been in continuous operation since that time. Increased amounts of trade wastes have required the extension of the plant at this time. The population equivalent of the industrial waste is somewhere in the neighborhood of 10,000 and the population of the city is about 2,000.

Professor W. L. Mallmann of the Department of Bacteriology, Michigan State College, continued a report given at the previous meeting of the association on the chlorination of sewage. He plans to conduct further studies at Battle Creek during the coming year.

Mr. C. K. Calvert, Superintendent of the Department of Sanitation, Indianapolis, Indiana, presented a paper on chemical precipitation with its relation to the dilution demands of the stream. This was one of the outstanding papers presented and was received with a great deal of favorable comment by those present.

Mr. George B. Gascoigne, Consulting Engineer, Cleveland, Ohio, presented a very interesting paper in outlining what comprises a good sewage treatment plant. This paper also was very well received and served to explain to operators some of the reasons why certain things are done in connection with the construction of a plant which the operator is not likely to understand when he takes over the operation of a plant. This paper was particularly valuable to the plant operators.

A Round Table discussion followed the papers and precipitated the usual enthusiastic discussion.

The annual business meeting was held and the following officers were elected for the ensuing year:

E. C. Miller, *President*
T. L. Jackson, *Vice-President*
W. F. Shephard, *Secretary-Treasurer*
Vincent Madison, *Director 1936–1937*
W. L. Mallmann, *Director 1935–1936*

W. F. Shephard,
Secretary-Treasurer

KANSAS WATER AND SEWAGE WORKS ASSOCIATION

Ninth Annual Meeting

Lawrence, Kansas, April 9–11, 1936

The Ninth Annual Meeting of the Kansas Water and Sewage Works Association and the Twelfth Annual Three-Day School was held at the University of Kansas, Lawrence, Kansas, on April 9–11, 1936. A total of 113 members and guests were registered.

The meeting opened at 9 o'clock on Thursday morning, April 9th. Mr. F. E. Willey, Water Superintendent of Lawrence, presided in the absence of Mr. F. W. Hoover, President of the Association. Dean George C. Shaad of the School of Engineering welcomed the members. Mr. Earnest Boyce, Secretary-Treasurer of the Association, read the annual report.

The papers on Tuesday were devoted principally to those dealing with water problems with the exception of the last two papers of the day, one of which was "The Administration of Municipally Owned Water and Sewer Utilities," by R. E. McDonnell of Burns and McDonnell, Kansas City, Missouri, and "The Operation of Sanitary Sewers and Sewage Disposal Plants on a Utility Basis," by B. L. Williamson of the State Board of Health.

The program on Friday was also devoted to water treating problems although the first paper of the day, "The Use of Ferric Coagulants in Alkaline Water," as discussed by J. M. Potter of the Pennsylvania Salt Manufacturing Company, Philadelphia, mentioned the use of these coagulants in sewage treatment.

On Friday evening the annual banquet was held in the Union Building at the University. Dr. E. H. Lindley, Chancellor of the University, greeted the members and guests on behalf of the University. Mr. K. K. Landes of the Department of Geology showed a two-reel colored picture entitled "Scenic Kansas." These views showed that Kansas is not so flat as is usually supposed by those who come from the East and wake up the next morning on the western plains.

The second feature of the evening was an illustrated lecture by Dr. F. W. Mohlman of the Sanitary District of Chicago entitled "Problems of the Chicago Sanitary District." Dr. Mohlman reviewed the history of the District. Views of the various treatment plants were shown and the new method of sludge disposal developed by the District was described in detail. The undigested sludge is filtered on vacuum filters, dried in "flash dryers," and burned in pulverized condition. The various steps in this development were explained, leading up to the new 40-ton plant at Calumet.

The Saturday session was devoted principally to sewage problems. The first paper was by Paul A. Diehl of Black and Veatch, Kansas City, Missouri, on "Treatment Required for Sewage Re-used for Irrigation Purposes." It was reported that one hundred localities in the United States most of which were in California and Texas were using sewage for irrigation purposes. Sewage used for field crops should have oil and grease removed, should have enough of the settleable solids removed so that they will not settle out in the irrigation ditches at a velocity of one foot per second. The B.O.D. of the sewage for field crops shall be such that the rate of demand for oxygen by the sewage shall not exceed the rate of oxygen absorption of the sewage as it leaves the irrigation ditches. For sewage to be used in the irrigation of garden crops the same two conditions shall hold as in the former case and in addition the sewage must be sterilized. It should also be filtered after sterilization in order to remove the organisms causing amoebic dysentery.

Dr. F. W. Mohlman discussed "Control Tests for Sewage Treatment Works." The importance of making B.O.D. determinations was stressed since this is the best method of determining the strength of sewage, the efficiency of various treatments, and the effect of effluents on streams. To correlate the B.O.D. with nitrogen and carbonaceous material in sewage the organic carbon should be determined. The oxygen consumed determination measures a variable proportion of the carbonaceous material and should be replaced by a determination of the organic carbon. A method for determining organic carbon in sewage and sludge was worked out about five years ago in the Sanitary District laboratories, and improved by work in England, but the technique is still a little complicated for use as a routine determination. In activated sludge plants the sludge index should be determined as a control test.

R. B. Lee, Designing Engineer, Hutchinson, gave a very interesting paper on the "Design Studies for Hutchinson Sewage Treatment Plant." It was interesting to note that the PWA grant warranted changing the type of plant from activated sludge to trickling filters, for economic reasons. This plant is now being constructed.

"Random Observations on the Design of Small Sewage Disposal Plants," by R. J. Paulette, was read by Mr. Earnest Boyce in the absence of Mr. Paulette.

A very short business meeting was held following the papers and the officers for the coming year were elected.

President—F. E. Willey, Water Superintendent, Lawrence.

Vice Presidents—D. H. Rupp, Production Engineer, Water Department, Topeka; C. A. Sanderson, Superintendent of Water Dept., Lyndon; H. H. Huffman, Superintendent of Water Dept., Topeka; E. W. Merrifield, Superintendent of Water and Light Dept., Wellington, Kansas.

Secretary-Treasurer—Earnest Boyce, Director and Chief Engineer, State Board of Health, Lawrence, Kansas.

Earnest Boyce,
Secretary-Treasurer

NEW YORK STATE SEWAGE WORKS ASSOCIATION

Preliminary Announcement—Spring Meeting

Lido Club, Long Island, June 11, 12, 13, 1936

Five years ago 175 of us travelled down the SUNRISE TRAIL to a Long Island Meeting, the first to have a display of manufacturers' exhibits.

Once again we follow the same trail to enjoy Long Island hospitality at the Lido Club Hotel just east of Long Beach. Chairman Lawrence Luther and his able committee have planned splendidly for our entertainment and the Program Committee has arranged two half-days of stimulating technical papers.

LONG ISLAND SECTION—Our only child, the "Long Island Section," is holding its quarterly meeting in conjunction with its parents' meeting. They expect a 100 per cent attendance.

MANUFACTURERS' EXHIBITS—The meeting opens with registration and inspection of manufacturers' exhibits Thursday afternoon.

THURSDAY EVENING we will have an informal "get-together" and dinner dance in the GRILL (à la carte).

TECHNICAL SESSIONS—*Friday* and *Saturday* mornings:

Friday noon the *Rating Committee* makes its first award to the operator who presented the report of plant operation receiving the highest rating for 1935.

Friday afternoon the men will join the ladies at Jones Beach for a tour of inspection and special water sports arranged for us by the Long Island State Park Commission.

Friday morning the *LADIES* will be guests of the local committee on a picturesque trip across the Island to Theodore Roosevelt's grave, and to Bethpage State Park where lunch will be served. Then to Jones Beach.

Friday night, informal banquet, entertainment and dancing. The floor show will be one of Broadway's best.

Saturday afternoon stay as long as you like and enjoy all of the recreational features of this unique country club by the sea.

A. S. BEDELL,
Secretary

Operators' Reports and Suggestions

W. D. Hatfield

FORT WORTH, TEXAS
EXCERPTS FROM REPORT OF THE SEWAGE DISPOSAL PLANT FOR THE FISCAL YEAR OCTOBER 1, 1934 TO SEPTEMBER 30, 1935

By W. S. Mahlie

Superintendent

Aside from the usual compilation of operating data, the major interest in the Fort Worth Sewage Disposal Plant is the progress being made in the elimination of odors.

During October, November and the first 15 days of December, 1934, the plant was operated in the usual manner, that is, the Imhoff tank effluent was aerated, with the return of a very small quantity of sludge from the final clarifiers. From December 15 to January 1, 1935, the Imhoff effluent was aerated but no sludge was returned. Beginning January 1, 1935 and continuing until September 30, 1935, the Imhoff effluent was by-passed around the aeration and secondary tanks and sprayed directly on the sprinkling filters. The result of this change was that the quality of the final effluent from the plant was somewhat reduced, but not to such an extent as to cause trouble in the Trinity River below the plant. It is quite significant, however, that no odor complaints have been received since this practice was started.

During December and January considerable quantities of grease were again received at the plant. Steps were taken to prevent a recurrence of the trouble.

Dilution water was added to the raw sewage from October 1, 1934 to January 18, 1935.

We have had considerable annoyance in the past from odors and oils due to "slugs" of waste coming from the Magnolia Refinery. This became quite acute during December, and they were cut off from our sewers. At the present time no wastes from any of the oil refineries are admitted to our sanitary sewer system, since such wastes contain substances which seriously interfere with our plant operation.

Due to the bad condition of Marine Creek and the Trinity River immediately below the mouth of Marine Creek, the City Legal Department took steps to force the offending companies to provide a different method of disposing of their wastes other than simply discharging them into ditches running into Marine Creek. Armour and Company built a dividing wall in the large stock yards drain, so that one side carries storm water while the other carries plant and sanitary wastes. This side is connected to their treating plant so that all the wastes must

pass through it. The Harry Rosenthal Packing Company moved to a new location and built a settling tank and grease trap, after which their wastes are taken into our sanitary sewers. The Blue Bonnet Packing Company was allowed to connect the line from their treatment tanks to our sanitary sewers. The Globe Laboratories and the City Packing Company received permission to connect to our sanitary sewers provided they build treatment units to remove grease and settleable material before discharging to our sewers. At the present time they have not completed their treatment plants.

Eight river surveys were made from Paddock Viaduct to Grand Prairie from April through September, 1935.

Samples were taken at twelve points; the results indicated that the river was in good condition at all times except on August 30, when a "slug" of pollution appeared to be moving down stream. A considerable amount of work was done during the past year in assisting the State Board of Health in making a survey of the Trinity River watershed; in analyzing samples of wastes from the packing houses and oil refineries, and in preparing plans for the improvement of the plant.

A number of tables are attached showing the pertinent data relating to the operation of the plant.

In Table I the total annual cost of operation in 1934–35 was $37,406.89 which was distributed as follows: salaries $23,693.93, supplies $1537.78, maintenance of building $1020.95, maintenance of equipment $10,454.10 and sundry charges $23.65.

TABLE II.—*Comparative Results of Operation, 1924 to 1935*

Period		Days Plant Operated	Sewage Treated Million Gallons per Day	Cost		B.O.D. p.p.m.	
From	To			Total	Per Million Gallons	Raw	Treated
5-1-24	4-30-25	355	5.142	$29,055.26	$15.92	392	38
5-1-25	9-30-25	149	6.571	14,248.87	14.55	461	52
10-1-25	9-30-26	357	6.060	27,366.42	12.65	532	38
10-1-26	9-30-27	352	6.735	26,347.04	11.11	445	37
10-1-27	9-30-28	329	6.824	29,662.03	13.21	508	34
10-1-28	9-30-29	52	4.469	21,024.34	*	342	33
10-1-29	9-30-30	295	8.070	45,081.35	18.94	380	33
10-1-30	9-30-31	355	10.637	51,568.61	13.66	418	30
10-1-31	9-30-32	291	10.693	55,153.67	17.73	339	27
10-1-32	9-30-33	354	10.630	59,126.90	15.71	377	25
10-1-33	9-30-34	365	9.330	44,145.42	12.96	332	17
10-1-34	9-30-35	350	10.424	37,406.89	10.25	372	31

* Only operated two months account construction new plant.

Table III shows the monthly cost of power, but is not reproduced in this review. The data show a drop in the monthly power from about 130,000 K.W.H. per month to 40,000 K.W.H. This reduction was obtained by bypassing the aeration plant.

TABLE IV (In part).—*Operating Data Digesters 1934–1935*

Month	Year	Temperature Digester Overflow ° F.			Total Gas Collected from Digesters Cu.Ft.	Gas Burned under Water Heaters Cu.Ft.	Gas Burned in Incinerator at Screen House Cu.Ft.
		No. 1	No. 2	No. 3			
Oct.	1934	92	92	91	3,161,200	636,500	437,440
Nov.	"	88	90	90	2,726,000	598,800	327,190
Dec.	"	—	87	85	2,618,000	871,600	307,430
Jan.	1935	—	89	88	2,488,800	936,400	311,850
Feb.	"	100	88	90	3,203,400	1,214,100	316,530
March	"	101	89	91	3,435,100	1,130,700	336,170
April	"	92	90	88	2,852,300	816,400	385,120
May	"	93	90	90	2,214,300	748,000	278,740
June	"	91	91	93	2,685,200	667,500	396,130
July	"	98	96	95	2,746,100	560,300	506,550
Aug.	"	95	98	100	2,416,000	508,300	494,680
Sept.	"	100	100	102	2,212,700	591,000	447,350
Average		95	92	92	2,729,925	773,300	378,765

A summary of the average sludge analysis is as follows: Imhoff sludge, 96.66 per cent moisture, 67.93 per cent volatile, pH 6.4; Imhoff tank skimmings, 97.7 per cent moisture, 67.78 per cent volatile, pH 6.6; digested sludge from digesters, 92.56 per cent moisture, 52.42 per cent volatile, pH 6.9.

TABLE V.—*H_2S Content of Sewage, 1934–1935*

Month	Year	Results in Parts per Million									
		Raw	Imhoff Effluent	Aeration Effluent	Secondary Effluent	Filter Effluent	Final Effluent	Supernatant Overflow	Secondary Basin Sludge	Final Clarifier Sludge	Reaerated Sludge
Oct.	1934	5.3	10.5	1.0	3.0	0.2	0.1	37.8	3.1	0.9	0.3
Nov.	"	4.3	9.9	3.9	4.1	0.2	0.1	26.7	10.0	0.8	0.8
Dec.	"	4.2	6.8	0.8	1.9	0.1	0.1	77.0	2.0	0.4	0.2
Jan.	1935	2.8	4.5	—	—	0.2	0.1	45.5	—	0.6	—
Feb.	"	1.5	3.5	—	—	0.1	T	47.7	—	0.4	—
March	"	1.6	4.0	—	—	0.1	T	29.9	—	0.5	—
April	"	3.2	6.5	—	—	0.1	0.1	25.7	—	0.5	—
May	"	1.9	4.1	—	—	0.1	T	26.5	—	0.5	—
June	"	2.6	6.2	—	—	0.1	0.1	25.6	—	0.4	—
July	"	5.2	8.3	—	—	0.1	0.1	25.3	—	0.4	—
Aug.	"	6.5	10.6	—	—	0.2	0.1	27.0	—	0.8	—
Sept.	"	5.1	9.2	—	—	0.2	0.1	43.5	—	0.5	—
Average		3.7	7.0	1.9	3.0	0.1	0.1	36.5	5.0	0.6	0.4

TABLE VI.—*Partial Summary of Analytical Data*
R—Raw F—Filter
I—Imhoff C—Final Clarifier

Month 1934–35	Suspended Solids				5-Day B.O.D.				N as Nitrite and Nitrate		Dissolved Oxygen		Chlorides	Temperature	Stability
	R	I	F	C	R	I	F	C	F	C	F	C	R	R	C
Oct.	300	129	54	34	359	243	30	21	9.7	9.2	1.4	1.5	361	82	98
Nov.	322	131	70	39	400	292	47	35	10.6	10.0	1.3	1.4	330	78	89
Dec.	350	159	93	49	527	382	71	52	5.7	5.5	1.0	1.2	326	70	44
Jan.	323	122	94	49	409	288	67	49	2.8	2.4	1.1	1.3	353	68	26
Feb.	301	115	84	40	241	161	39	23	5.1	5.3	1.4	1.6	293	68	64
Mar.	344	127	97	43	333	218	41	28	8.1	8.1	1.1	1.3	342	73	88
Apr.	392	133	92	40	421	267	53	23	7.7	7.3	1.2	1.4	378	77	87
May	303	115	71	36	316	212	46	29	4.6	4.5	1.5	1.6	371	75	76
June	313	115	86	44	310	211	37	24	4.6	4.4	1.2	1.4	424	80	70
July	341	121	92	41	357	231	29	19	7.6	7.1	0.8	1.1	516	84	93
Aug.	359	118	89	46	410	247	39	31	6.3	5.8	0.6	0.7	501	88	63
Sept.	353	124	92	44	378	250	43	29	9.3	9.1	1.2	1.4	388	83	86
Average	333	126	85	42	372	250	45	31	6.8	6.6	1.2	1.3	382	77	74

Analyses of supernatant overflow liquor show an average of 7984 p.p.m. suspended solid, maximum month 22,004 and minimum month 3316 p.p.m. Ammonia nitrogen varied from 233 to 487 p.p.m., organic N from 233 to 910 p.p.m., and pH from 6.8 to 7.0.

TABLE VII.—*Partial Summary of Operating Data*

Month 1934–1935	Sewage Treated Million Gallons Average	Detention Time Imhoff Tanks Hrs.	Settling Time Secondary Tanks Hrs.	Rate of Dosing Filters M.G. per Acre Day	Settling Time Final Tanks Hrs.
Oct.	10.800	1.75	2.89	2.553	2.05
Nov.	10.984	1.72	2.85	2.597	2.01
Dec.	10.153	1.86	3.08	2.400	2.18
Jan.	10.063	1.88	3.11	2.379	2.20
Feb.	10.750	1.76	2.92	2.541	2.06
Mar.	10.038	1.89	3.12	2.373	2.20
Apr.	9.794	1.93	3.20	2.315	2.26
May	12.585	1.50	2.49	2.975	1.76
June	12.456	1.52	2.52	2.945	1.78
July	10.034	1.89	3.12	2.372	2.20
Aug.	9.119	2.08	3.44	2.156	2.43
Sept.	9.399	2.01	3.33	2.222	2.35
Average	10.424	1.82	3.01	2.486	2.12

FLINT, MICHIGAN
EXCERPTS FROM ANNUAL REPORT OF THE SEWAGE TREATMENT PLANT, 1935

By Pierre R. Welch

Superintendent

The eighth year of operation of the Flint sewage treatment plant was satisfactory, considering the many difficulties that had to be overcome.

Pumping Station.—The operation of the pumping station was exceedingly satisfactory and without any major breakdowns. The average daily pumpage was 9,900,000 gal., compared to 9,310,000 gal. per day for 1934. The power consumption was 253 K.W.H. per mil. gal. of sewage pumped or 5.8 K.W.H. per mil. gal. ft. head. The oil consumption of the Diesel was 0.17 gal. per K.W.H. generated. A total of 513 cu. ft. of screenings or 0.14 cu. ft. per mil. gal. of sewage was removed.

Table I.—*Summary, 1928–1935, Pumping Station Data*

	1928	1929	1930	1931	1932	1933	1934	1935
Total mil. gal. of sewage pumped	3,510	3,694	3,551	3,654	4,304	3,543	3,398	3,615
K.W.H. per mil. gal. pumped	263	263	286	264	255	258	261	253
K.W.H. per mil. gal. ft. head	6.0	6.0	6.5	6.0	5.8	5.9	5.9	5.8
Cu. ft. screenings removed	351	753	973	993	725	815	814	513
Cu. ft. screenings per mil. gals.	0.10	0.20	0.27	0.29	0.17	0.23	0.24	0.14

Imhoff Tanks.—The Imhoff tanks continue to be our main source of trouble because of foaming. The problem became so acute and critical at times that it was necessary to put some of the tanks out of service until the foaming could be brought under control. The efficiency of the Imhoff tanks was remarkably high considering the difficulties which were encountered during the year. The average daily removal of suspended solids was 15,600 lbs. per day and 13,100 lbs. of the 5-day B.O.D. The per cent removal of suspended solids was 75 per cent and for the 5-day B.O.D. it was 50 per cent

Rex Traveling Screen.—A total of 102 cu. ft. of screenings was removed from the Imhoff tank effluent, or an average of 8.5 cu. ft. per month. The screenings were disposed of by burying in pits. The Rex screen has decreased the work on the filter beds tremendously. It has proven to be an indispensable piece of equipment when the Imhoff tanks are foaming.

Digested Sludge Drawing and Disposal.—The sludge drying beds were used very extensively during 1935. The amount of sludge which foamed over the gas vent walls and which was skimmed either to the drying beds around the tanks or to the field, could not be determined because there was no means of measuring it, consequently the data on the amount of digested sludge drawn from the tanks will show lower

figures than those which would be obtained during a normal year without foaming.

A total of 45,356 cu. yd. of digested sludge was drawn from the Imhoff tanks, exclusive of the sludge that was skimmed and could not be measured. Sludge drawn to the beds was 14,879 cu. yd. and to the field 30,477 cu. yd. The digested sludge averaged 95.4 per cent moisture and 62.0 per cent organic. A total of 3,521,000 lb. of solids on a dry basis was drawn from the tanks. A total of 4,446 cu. yd. of dry sludge was lifted from the drying beds with a moisture content of 62.3 per cent and an organic content of 44.8 per cent. Due to the fact that it was necessary to remove the sludge from the drying beds as quickly as possible, a great deal of sand was lost because the sludge contained a higher moisture content. The sludge which was skimmed from the tanks was mixed with oil and did not dry readily. Nearly all of it had to be shoveled into the industrial cars.

For more detailed information, refer to Table II.

TABLE II.—*Summary, 1928–1935, Solids Removed*

	1928	1929	1930	1931	1932	1933	1934	1935
	Solids Deposited in Imhoff Tanks							
Total lb. in thousands	6,240	5,390	4,416	6,204	5,797	5,095	5,749	5,705
	Digested Sludge Removed from Imhoff Tanks							
Total cu. yd.	35,169	25,725	36,031	33,968	38,839	35,729	64,967	45,356
Total lb. in thou., dry basis	4,200	3,080	4,370	3,305	5,436	3,230	5,362	3,521
Per cent moisture	92.9	92.7	92.8	94.0	92.3	94.4	95.0	95.4
Per cent organic	49.1	48.7	48.3	53.0	43.9	53.2	55.5	62.0
	Sludge Removed from Drying Beds							
Total cu. yd.	6,760	8,357	10,021	9,146	5,520	5,553	1,013	4,446
Per cent moisture	—	51.7	58.4	63.0	51.0	56.9	51.6	62.3
Per cent organic	—	34.6	40.2	46.0	39.0	42.8	48.5	44.8
	Sludge Removed from Secondary Tanks							
Total cu. yd.					11,697	7,330	12,296	10,590
Total lb. in thou., dry basis					1,096	439	572	494
Per cent moisture					94.4	96.9	97.2	97.2
Per cent organic					50.3	70.7	73.2	71.8

Aeration Unit.—Comparatively little trouble was experienced with the aeration unit in contrast to the past two years. Two compressors were in operation from July 13th to October and the rest of the year only one compressor was in operation. The aeration unit gave very satisfactory operation and the results were good. The compressors were in operation from 7:00 A.M. to 12:00 midnight. The average dissolved oxygen content of the aeration tank effluent on the 24-hour com-

posite sample was 6.0 p.p.m. compared to 5.3 for the previous year. Pre-aeration in conjunction with chlorination controlled odors adequately.

Filters.—Both filters were in operation throughout the year. The filters started to slough the latter part of April and continued throughout July. The maximum amount of solids sloughed off in June when a total of 136,500 lb. on a dry basis was removed by the final settling tanks. The percent removal of 5-day B.O.D. was 70 per cent compared to 69 per cent the previous year.

The filter influent was chlorinated during the summer months. The filter beds were harrowed in the spring.

Secondary Setting Tanks.—A total of 493,500 lb. of solids on a dry basis was removed by the final settling tanks. The secondary sludge totalling 10,590 cu. yd. with a moisture content of 97.2 per cent and an organic content of 71.8 per cent was pumped back to the incoming raw sewage at the gate house and then settled out in the Imhoff tanks where it was digested and stabilized. No trouble was experienced from the secondary tanks and the operation was highly satisfactory.

Chlorination and Odor Control.—Chlorination season for 1935 started June 4 and ended October 17. All of the chlorine valves, which have always given a great deal of trouble, were replaced with Nordstrom plug type valves in April. These valves gave the same troubles and in September they were all replaced with Chlorine Institute valves which have been working very nicely to date. The chlorine machines were overhauled in the spring. All copper tubing and connections were replaced with standard flared fittings which can be purchased locally.

1. Chlorination of the Filter Influent to a Residual.—The filters began to pool during the latter part of May. The filter beds were harrowed June 4 and chlorination was started June 11. An average residual of 2.2 p.p.m. of chlorine was maintained as found necessary. Pooling was readily controlled by this method. Whenever the filters showed a discoloration due to the slimy growth and accumulation of solids, the filters were chlorinated to a residual until the growths were eliminated.

The rate of sloughing of solids by the filters was greatly increased by chlorination so that most of the solids sloughed off in June and July.

2. Partial Chlorination of the Filter Influent for Odor Control.—The problem of odor control about the filters was much more difficult this year due to the extreme foaming condition of the Imhoff tanks, which resulted in a higher organic load on the filters, thus increasing the odors. Partial chlorination to an average of 6 p.p.m. in addition to pre-aeration was successful in minimizing odors to a point where they caused no nuisance. This procedure was carried out from June to October 17.

3. Chlorination of the Plant Effluent to a Residual.—The plant effluent was chlorinated to a residual from September 17 to September 26. A total of 1,745 lb. of chlorine was used which gave a residual of 0.5 p.p.m. The chlorine demand was 3.0 p.p.m.

TABLE III.—*Summary Table 1932–1935 of Plant Effluent Analysis*

	1932	1933	1934	1935
1. pH	7.8	7.9	8.0	8.1
2. Chlorine Demand in P.P.M.	4	3	3	3
3. Ammonia Nitrogen in P.P.M.	4	3	5	4
4. Nitrate Nitrogen in P.P.M.	12	12	9.2	12.7
5. Nitrite Nitrogen in P.P.M.	0.8	0.7	0.8	0.78
6. Suspended Solids in P.P.M.	39	29	32	32
7. 5-day B.O.D. in P.P.M.	51	45	48	42
8. Dissolved Oxygen in P.P.M.	6.3	7.3	6.3	6.6
9. Avg. lbs. suspended solids per day in plant effluent	3,760	2,370	2,600	2,600
10. Avg. lbs. 5-day B.O.D. in plant effluent	5,000	3,640	3,700	3,400
Average daily per cent and pounds of suspended solids and 5-day B.O.D. removed by the plant as a whole				
1. Pounds of 5-day B.O.D.	17,200	18,930	23,400	23,000
2. Per cent of 5-day B.O.D.	78%	84%	87%	87%
3. Pounds of suspended solids	18,350	15,780	18,900	19,200
4. Per cent of suspended solids	83%	88%	89%	88%

TABLE IV

A. Fixed Charges	1932	1933	1934	1935
Interest and amortization yearly	$104,370.00	$ 96,543.75	$ 93,206.25	$ 91,868.75
Cost per mil. gal. of sewage treated	24.30	27.10	27.40	25.40
Cost per capita contributing	0.80	0.74	0.72	0.71
Cost per capita of designed capacity	0.65	0.60	0.58	0.57
B. Operating Charges	1932	1933	1934	1935
Cost of operation and maintenance	$ 23,311.74	$ 18,468.09	$ 25,622.45	$ 26,531.81
Cost per mil. gal. of sewage treated	5.42	5.21	7.54	7.34
Cost per capita contributing	0.18	0.14	0.20	0.20
Cost per capita of designed capacity	0.15	0.12	0.16	0.17
C. Total Charges including *A* plus *B*	1932	1933	1934	1935
Total	$127,681.74	$115,011.85	$118,828.70	$118,400.56
Cost per mil. gal. of sewage treated	29.72	32.31	34.94	32.74
Cost per capita contributing	0.98	0.88	0.92	0.91
Cost per capita of designed capacity	0.80	0.72	0.74	0.74

Capital Investment

First Unit, including Imhoff tanks, water supply system, Administration Building, drying beds, etc.	$ 541,887.01
Second Unit, including Aeration tank and building, filters, secondary settling tanks, chlorine building, chlorine reaction tank, etc.	643,000.00
TOTAL	$1,184,887.01

A grand total of 39,960 lb. of chlorine was used during 1935.

River Studies.—A total of 37 river studies were made during the year. The river was in very good condition and at no time was there any danger of odors coming from the river due to zones in which the oxygen content was depleted.

Efficiency of the Plant.—The Imhoff tanks have been in operation for eight years and the secondary unit including pre-aeration, trickling filters, secondary settling tanks and chlorine reaction tank has been in operation for four years. Table III gives a summary of the plant effluent analyses from 1932 to 1935; the average daily per cent and pounds of suspended solids and 5-day B.O.D. removed by the plant as a whole are also included.

Costs.—Capital and operation costs are summarized in Table IV.

Analytical Data.—Average monthly results for B.O.D. and suspended solids in 1935 are shown in Table V.

TABLE V.—*B.O.D. and Suspended Solids, Year 1935, Parts per Million*

Month	5-day B.O.D.				Suspended Solids			
	Raw	Imhoff Eff.	Filter Eff.	Final Eff.	Raw	Imhoff Eff.	Filter Eff.	Final Eff.
Jan.	319	156	44	51	252	65	30	26
Feb.	360	189	54	54	265	72	30	25
Mch.	194	117	30	26	194	60	29	23
Apr.	356	186	54	42	274	75	40	27
May	338	198	63	50	255	84	64	40
June	343	193	64	50	258	73	83	52
July	306	170	45	32	278	71	56	38
Aug.	300	136	36	27	250	51	41	31
Sept.	334	151	37	32	270	51	31	27
Oct.	348	151	46	42	267	55	33	28
Nov.	310	130	48	42	250	54	39	32
Dec.	328	147	57	50	233	61	40	32
Avg.	320	160	48	42	254	64	43	32

A GERMAN SLUDGE SLINGER

THE INTRODUCTION OF FRESH SLUDGE INTO SLUDGE DIGESTION TANKS *

By Baurat Werner Müller

Nürnberg

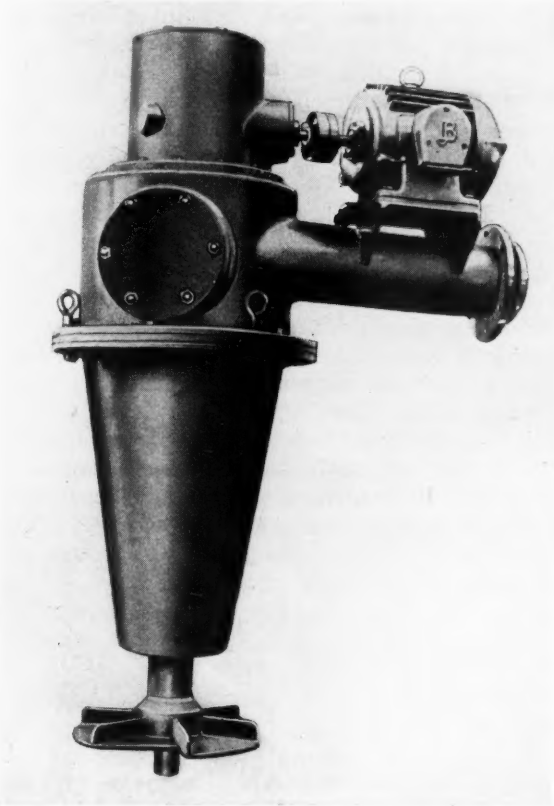
In two-story clarification plants fresh sludge enters the digestion tank continuously and is uniformly distributed on the surface of the old sludge. Through biological processes and temperature changes, a very pronounced agitation, especially in the upper layers of the

* Separate Reprint from "*Die Städtereinigung,*" Vol. 18 and 19, year 1935.

sludge, results. The fresh sludge is thereby mixed with the digesting sludge and is immediately started toward methane fermentation.

In the discharge of the sludge, only the oldest and most decomposed sludge is removed. As a result of the introduction and distribution of sludge in the digestion compartment, the action of an Imhoff tank in general is quite satisfactory where normal conditions exist.

In separate digestion tanks, however, the introduction of fresh sludge does not take place continuously and herein lies a great disadvantage for separate digestion tanks.



The usual method of introduction of fresh sludge is through a pipe in the cover of the container or through a pipe from the side. It is evident that the distribution of the fresh sludge is very imperfect. If supernatant liquor is withdrawn as fresh sludge is introduced the fresh sludge will flow towards the direction of discharge. Likewise, some parts of the tank will be filled with old sludge which hardly changes its position.

Attempts to overcome this poor distribution of sludge in separate digestion tanks have been by (1) high velocity inlet against baffles,

(2) mixing fresh and digested sludge before pumping into tank, (3) stirring mechanisms, and (4) recirculating mechanisms. Since October 1, 1935, a new method of introduction of sludge (German Patent) has been tried at the clarification plant of Nürnberg-Nord.

The fresh sludge is introduced through a distribution mechanism located in the center of the cover (Fig. 1). This consists principally of a distribution plate, movable around a vertical axis and driven by a motor. The sludge flows towards the distribution plate and is, by the revolving motion, distributed like rain over the whole surface of the digesting sludge. The tank is 11.0 metres in diameter. One hundred and forty cbm. fresh sludge per hour is introduced, usually in a period of two hours per day. The current required is only 3 K.W., that is 6 K.W. hours per day. The water surface is lowered 50 cm. before the charge by discharge of digestion liquor.

A heavy scum layer cannot result, due to the repeated new charges of fresh sludge on the top of the tank contents, but a relatively moderate solids layer (about 50 to 70 cm.) is formed, which cannot be classified as scum. This surface layer is valuable and must not be lost. It is one of the main carriers of biological life in the digestion tank.

Results of Operation.—The tank operated according to the old way is designated in the following as "Tank I" and the tank operated according to the new process as "Tank II."

The experiments were started October 1, 1934. Before starting the experiment, the scum layers up to 3 m. thick were agitated with the water spray in all tanks. Results of operation are shown in Table I. It is to be seen from the table that the fresh sludge quantities were approximately the same in both tanks. The temperatures in the tanks, measured by electrical thermometers imbedded 4 meters deep into the sludge, were the same in the various months. The average temperatures was 25.5 deg. C. The efficiency of the digestion tanks is shown by the quantity of gas produced.

TABLE I

Month	Tank I		Tank II		Plus Production in Per Cent
	Fresh Sludge Cbm.	Gas Cbm.	Fresh Sludge Cbm.	Gas Cbm.	
October, 1934	3210	36,103	3330	43,079	19.3
November	2970	39,610	2970	46,349	17.0
December	2880	46,731	2970	49,627	6.2
January, 1935	2580	35,900	2640	41,482	15.5
February	2430	29,460	2220	32,693	11.0
March	2730	38,470	2850	44,249	15.0
April	2190	39,263	2190	40,588	3.4
May	2160	32,790	2190	38,527	17.5
June	3000	41,009	3030	47,699	16.3
July	3810	59,868	3540	66,228	10.6

Note. One cubic meter equals approximately 35.3 cu. ft.

The increase in gas production in Tank II was between 3.4 and 19.3 per cent. The increase in December was only 6.2 and in April only 3.4 per cent. This was partly due to the necessity of agitating the contents of Tank I with the water spray, because an extremely viscous scum had formed. After each agitation of the scum, a considerable and persistent increase in gas formation was noticeable. It is clear that after agitation of the large quantities of organic matter, accumulated in the scum, a very violent decomposition takes place. According to the fresh sludge quantity, as compared with other months (for instance November) a gas production in December of about 40,000 cbm. should have been obtained. The actual gas production in December was 46,731 cbm.; about 6,730 cbm. was obtained, therefore, from the scum. On April 15 and 16, again heavy scum had to be agitated in Tank I. Based on the amount of fresh sludge, a gas production of 33,000 cbm. at the utmost should have resulted (compare with the months of February and May); however, 39,263 cbm. was produced. In the month of April about 6,260 cbm. of gas was produced from the scum. In all other months, the gas production in Tank II was from 9 to 11 per cent greater than in Tank I.

The CO_2 content of the gas in Tank II was always somewhat lower than in the gas from Tank I. In the period extending from Jan. 24 to Feb. 22, 1935, 22 tests were made. During this time the gas of Tank II contained 32.9 per cent CO_2, while the gas of Tank I averaged 34.3 per cent. The carbon dioxide in the gas from Tank II was partly absorbed by the water.

During the time of observation, now extending over 10 months, the tanks were repeatedly opened. It was established that Tank I always showed scum layers of several meters thickness and of viscous character. Twice during the observation time, the scum layers had to be agitated (November 26/27 and April 15/16). Since a greater charge occurred June 15 and subsequently, Tank I was greatly overcharged. Three times during this short period, a foamlike sludge made its way up to the gas dome (April 7, 1935, July 23, 1935 and August 5, 1935). This foamy sludge had a bad odor. The solid viscous scum layer disappeared completely. The whole upper part of the tank was filled with foamlike sludge. We ascribe this behavior to the fact that during the summer months the fresh sludge was very warm (19° to 20° C.) and reached the tank in this condition. If the fresh sludge is charged at a temperature of only 8° to 12° C. very likely heavy scum layers will again be formed. Although the operation of Tank I at this time presents great difficulties, these experiments will be continued.

During the observation time Tank II, provided with sludge distributing mechanism, never showed layers of floating sludge but only, as previously mentioned, thin, easily mixed sludge of moderate depth, which could not be determined because the sludge layer was approximately of the same consistency as the supernatant liquor. When the last inspection was made on August 5, 1935, it was established that in Tank II after ten months operation, there was no scum whatever. Sludge was drawn in well digested condition. Solids consisted of 49

per cent organic and 51 per cent mineral matter (computed to sandfree residue—organic matter was 70 per cent and the sand was 28 per cent of the mineral contents).

Tank II has not as yet been utilized to the limit of its capacity. Each tank now receives 270 cbm. instead of 240 cbm. per day. This corresponds to the sludge production of about 125,000 inhabitants. Therefore, a digestion capacity of 0.43 cu. ft. per capita would be required.

As far as can be judged up to the present, the limit of efficiency has not yet been reached.

OPERATORS' NOTES

E. E. Smith, of Elgin, Ill., writes:

A problem that we were one of the first to work on was scum in the gas vents. Most plants that I visited in Illinois did nothing to eliminate scum and it reached several feet in thickness and of course hindered gas removal. We started pumping this scum off the vents twice yearly and found that operation troubles were eliminated and that the tanks had a much better appearance and less odor. This has now become common practice at some of the other plants. Our present practice is still to pump twice yearly and dry on beds and our scum never gets over a few inches in thickness."

Harry E. Schlenz, of P.F.T. writes:

"1. *Transferring and Sampling of Sludge.*—The Durham, North Carolina plant, designed by W. M. Piatt of that City, apparently has been designed from the standpoint of the operator. One innovation of special importance to the operator is the sludge control house, which contains three tanks of approximately 15,000 gallons capacity each. Sludge from the clarifier or from other parts of the plant is brought into two of these tanks for conditioning and sampling before it is transferred to the digesters. The tanks can be stirred up and a proper sample taken. Sludge can also be equalized between the two tanks so that in going into two digesters an equal loading is given. Sludge from the digesters also passes into these tanks and is sampled before going on to the sludge bed.

"2. *Digester Control.*—The operation of the digester was more or less controlled by a recording gas calorimeter. It was found that unfavorable conditions existing in the digestion tank could be told almost instantly by the recording gas calorimeter, while it might be quite a long time before such a condition would show up on a pH determination or by observation.

"3. *Supernatant Liquor Problem.*—In a number of plants attempts are being made to reduce the amount of supernatant liquor or the solid content of the supernatant liquor going back into the treatment process. At Cleveland, Ohio, this is to be accomplished by means of four large pre-concentration tanks which take the raw and activated solids in a continuous way thus separating some of the liquor before the sludge is passed into the digesters.

At other plants supernatant liquor is taken from the digester and held in a decantation tank for a short time. The sludge solids are returned to the digester while the liquor is passed back into the raw sewage. This method is being used at Fort Atkinson, Wisconsin.

Two-stage digestion is being used for the same purpose to get less activity in the second tank, which allows a separation of the supernatant liquor from the sludge solids. From data which the writer has seen this seems to be about the only justification for two-stage digestion.

From theoretical considerations it has been indicated that a small primary unit and a large secondary unit should be used in two-stage processes. However, actual operating data indicate that it is more desirable to have a large primary unit and smaller secondary capacity, thereby reducing the pounds dry solids loading per cubic foot in the primary unit. At Durham, North Carolina, two out of three similar sized tanks are used for primary digestion and the third tank for secondary. A very fine supernatant liquor, low in solid content, is obtained from this third tank."

Reviews and Abstracts

H. W. Streeter

LABORATORY TESTS FOR ASCERTAINING THE CONDITION OF ACTIVATED SLUDGE

By Edward Ardern and William T. Lockett

Paper presented at a meeting of the North Western Branch, Institute of Sewage Purification, March 21, 1936.

The authors present the results of a study of six characteristics of activated sludge, the determination of which might aid in diagnosing its quality. As a basis of standardization of various types of sludges, the proportion of dry organic matter (D.O.M.) was adopted, and the standard of a D.O.M. content of 0.7 per cent was selected which, combined with the normal contained mineral matter, would represent a sludge having 10,000 p.p.m. of dry solids. Before its characteristics were determined, the sludge sample was adjusted to this standard D.O.M. content by means of a preliminary suspended solids and D.O.M. determination.

Having standardized the sample to the 0.7 per cent D.O.M. content (or to any other desired percentage below 0.7 per cent) the following characteristics were ascertained:

1. *Rate of Settlement Test.*—To approximate the conditions in the aeration tank 250 ml. of the standardized sludge were mixed with 750 ml. activated sludge effluent and the percentage of settlement in 1000 ml. graduated cylinders read at the end of 5, 10, 20, 30 and 60 minutes. For direct comparison purposes the 30 minute reading was found to be the most serviceable. The test is very useful as a rapid and accurate indicator of abnormalities in sludge condition although bad and putrefactive sludges have frequently a higher rate of settlement. These latter, however, would not be classified as good because of odor.

2. *Drainability or Filtrability Test.*—This test is based on the assumption that a good sludge filters more rapidly than an inferior one, and that the filtration rate is proportional to the sludge quality. Filtration of sludge through filter paper in a Buchner funnel under standard conditions was employed. The times taken to filter 25 ml., 50 ml., etc. up to 90 ml. of liquid were noted. The test is somewhat uncertain owing to the influence of grease in the sludge, but a high rate of filtration is definitely associated with sludge in good condition and with low grease content.

3. *Biochemical Oxygen Demand Test.*—The 5-day B.O.D. test was determined on standardized sludge samples by the dilution method, using 50 ml. of the sludge diluted with 950 ml. of Manchester tap water and 500 p.p.m. sodium bicarbonate. This test, while very useful, cannot be used to differentiate good sludges from those thoroughly bad and putrefactive since both good and bad sludges give low B.O.D. figures.

4. *Oxygen Absorption from Acid Permanganate Tests.*—For this test, 50 ml. of the above 5 per cent diluted sludge was treated with 50 ml. of N/80 permanganate acidified with sulphuric acid, and observations made at 4 hours and 3 minutes. These tests were found to be of little value.

5. *Dissolved Oxygen Content of Original Mixed Liquor Test.*—This test was made on the supernatant of the sludge sample as originally taken from the aeration tank, employing the Winkler method with the nitrite modification. These results were found to be definitely indicative of the state of oxidation or condition of the sludge (as was previously established by these authors). The test is of definite value but only rather broad generalizations are possible.

6. *Microscopical Examination.*—General appearance of the original fresh sludges, without standardization was observed, noting the presence of fungus, and prevailing types of protozoa. Of all the tests this one is considered the most valuable. The following classification of sludge based on such examinations has been made by the authors:

(A) *Sludge in bad condition:* Preponderance of Flagellates, Amoebae (and other Rhizopods): relatively few Ciliates, e.g., Carchesium, Chilodon, Choenia absent.

(B) *Sludge in unsatisfactory condition:* Flagellates, Amoebae (and other Rhizopods): Some Ciliates, e.g., Stentor, Paramoecia, Chilodon, Carchesium, Vorticella: Choenia absent.

(C) *Sludge in satisfactory condition:* Few flagellates and Amoebae (and other Rhizopods): preponderance of Ciliates, e.g., Carchesium, Vorticella, Chilodon, Colpoda, Colpidium: some Aspidisca and Loxophyllum: occasionally Choenia: few Suctoria.

(D) *Sludge in good condition (e.g., when nitrification is well established):* Very few flagellates: Amoebae rare: preponderance of Ciliates, e.g., Carchesium, Vorticella, Aspidisca, Loxophyllum, Choenia: few Suctoria.

The authors conclude that normally, a sludge in good condition is characterized by

(*a*) ready settlement of the flocs,
(*b*) rapid filtrability, with stated qualifications.
(*c*) relatively lower oxygen demand,
(*d*) presence of certain types of larger ciliates, and scarcity of flagellates, amoeba and filamentous forms.

J. K. Hoskins

ACTIVATED SLUDGE RESEARCH ON THE PRACTICAL SCALE

By W. Watson

Paper presented before the Public Works, Roads and Transport Congress, November 22, 1935. Abstracted, with discussion, in *The Surveyor*, **88**, 609–10 (November 29, 1935), **88**, 667–68 (December 13, 1935), and **89**, 13–14 (January 3, 1936).

With so little really known concerning the fundamentals of activated sludge operation, the author deprecates the blind acceptance of this method of sewage treatment with is high costs and generally unfavorable comparison with tank and percolating filter units. He points to the possibilities of effecting revolutionary and rapid improvements in the activated sludge process and the need for experimental work on a comparable basis to speed these developments. Observations at a full scale plant of the "Simplex" type are then discussed.

Purification of Sewage and Time of Contact.—The sewage dealt with is principally domestic, containing some spent gas liquor, brewery, bleach and dye wastes and has a 4-hour oxygen absorbed strength averaging 115 p.p.m. and ranging from 90 to 160 p.p.m., during different parts of the week. A definite percentage reduction in oxygen absorbed, about 85 per cent, has been observed to result from the treatment process regardless of the strength of the dry weather flow when the detention time is 15 hours. If this time is reduced to 12 hours, the purification drops to around 70 per cent. With sewage containing storm water this relationship does not apply for with the contact period with activated sludge reduced to one-third, 85 per cent purification is still obtained. These observations on a plant scale confirm previous laboratory results of numerous other workers.

Description of Plant.—Experiments were conducted in a full size surface aeration plant treating 2¼ m.g.d. of dry weather flow sewage. The plant has 5 separate units, each of which has 8 tanks in series with an aerating cone to each tank. The tanks are 25 ft. square at the top, 12½ ft. deep and separated by division wells extending up to 9 in. below the water level, thereby preventing short circuiting of flow. Samples, each composited over 24 hours, for periods of many weeks were examined by the 4-hour oxygen absorbed test so that every kind of condition possible could be observed. These results are tabulated in terms of percentage purification, both when spent gas liquor was present in and absent from the sewage. A plot of these data shows that without gas liquor 82 per cent purification is obtained in the first 8 hours and only 84–85 per cent in 16 hours, so that the latter half of the time is spent in reconditioning the sludge. This must be true for if the total aeration time is reduced by half, purification is very materially reduced.

In this plant 120,000 gallons of good sludge are run to waste daily and attempts were

made to effect partial purification with it before such disposal. The flow through one of the 5 units was doubled, using the fully reconditioned sludge from the other 4 normally operated ones and the resulting sludge from this unit wasted. The surplus sludge from the 4 units was ample to maintain the 10 per cent working volume in the unit taking double the flow. Tabulated results show that very good results are obtained (76 per cent as against 81 per cent normal) with this 8-hour aeration period, especially when the sewage tends to be weak and contains no gas liquors. With gas liquors present (0.8 per cent) the percentage purification is only 67 per cent as compared with 77 per cent for full treatment. In these cases, however, the dissolved oxygen absorbed test results show wide differences in results as between partial and complete treatment.

Rate of Absorption of Oxygen by Activated Sludge.—Accuracy of values in this test require rapid separation of the sludge from the aerated water or liquid at the end of the absorption period. To stop this absorption suddenly, a chemical is employed that will kill bacteria and yet not interfere with the dissolved oxygen or its estimation. Mercuric chloride was tested for this purpose from which it was determined that (1) mercuric chloride had no effect on the D.O. determination in tap water but causes a lower result in aerated final effluents, (2) although bacterial action is inhibited at once some dissolved oxygen is used up (30–50 per cent) when sludge is introduced into disinfected aerated final effluents unless the mercuric salt is precipitated by caustic soda, in which case the D.O. determination is accurate, (3) mercuric chloride interferes with the modified Miller method of D.O. determination.

Various tests were made to ascertain the rate of oxygen absorption of sludges from different stages of the aeration process in combination with supernatant liquids.

(*a*) Sludge from tank No. 1 in No. 1 tank liquid,
(*b*) Sludge from tank No. 8 in No. 8 tank liquid,
(*c*) Sludge from tank No. 8 in No. 1 tank liquid,
(*d*) Sludge from tank No. 1 in No. 8 tank liquid.

These tests were each made with well aerated liquids, carefully syphoned into two half Winchester bottles filled full. Into one bottle 25 cc. of 7.5 per cent $HgCl_2$ was placed then 100 cc. of the settled sludge. To the other bottle 100 cc. of the same sludge was introduced and shaken gently for 5–10 minutes and then 25 cc. of $HgCl_2$ solution added to stop the reaction, and afterwards 4 cc. of 40 per cent NaOH added to each. From the difference in oxygen content the amount of oxygen absorbed by that amount of sludge (dry solid weight) in any particular time of contact was calculated and thence in terms of oxygen in grams absorbed per minute per gram of sludge. The dry weight of the sludge used was obtained in each case. Some of these results are reproduced in the following table, in which is given also the oxygen absorbed in 4 hours from permanganate of the liquid into which the sludge was placed:

No. of Expt.	(*a*) No. 1 Sldg. in 1 Liq.	(*b*) No. 8 Sldg. in 8 Liq.	(*c*) No. 8 Sldg. in 1 Liq.	(*d*) No. 1 Sldg. in 8 Liq.	O.A. in 4 hrs.	
					1st Liq.	8th Liq.
A.	.00056	.00026	.00056	.00042	3.00	1.88
B.	.00041	.00021	.00057	.00029	2.2	1.12
C.	.00086	.00078	.00070	.00069	3.62	3.84
D.	.00093	.00068	.00089	.00079	4.40	3.16
E.	.00088	.00024	.00078	.00072	3.94	1.48

Notes: Exp. B. was run with weak sewage after a 2-day rain.
Exp. D. employed strong sewage with 0.75 per cent gas liquor.
Exp. C. where liquid in tank 8 happened to be stronger than that in tank 1.

From these results the following conclusions are drawn:

1. In general the rate of oxygen absorption by activated sludge depends upon its "condition" at the time,
2. A reconditioned sludge, if put into an unpurified liquid, immediately has a much larger demand for oxygen.
3. A reconditioned sludge in its own accompanying liquid has a much less avidity for oxygen than one which is purifying sewage.

Distribution of Oxygen in an Aeration Plant.—These tests were made on samples collected in bottles filled with CO_2 and 25 cc. of a 7.5 per cent solution of $HgCl_2$. The stoppered bottles were immersed to any desired depth, the stoppers withdrawn and when filled, the contents thoroughly mixed with the mercuric chloride.

Aeration of Purified and Unpurified Sewage.—The rate of oxygen solution in various types of liquids was also studied. With identical volumes of liquid, temperatures, etc., and starting with completely deaerated samples, air was bubbled through the following liquids, which after a definite period of aeration (not given) contained the following amounts of dissolved oxygen expressed in p.p.m.

1. Strong colloidal tank effluent (Monday wash water)	2.2
2. Strong but less colloidal tank effluent	2.9
3. Liquid from aeration tank No. 1, about half purified	3.5
4. Liquid from aeration tank No. 4	3.7
5. Good sparkling final effluent	3.9

These results demonstrate that a good deal more energy (probably more than double) is required to dissolve a definite amount of oxygen in a strong sewage than in a good final effluent.

Having determined these relationships, the author discusses the possible advantages and disadvantages of the Series Treatment in aeration processes of sewage treatment such as in the Simplex and Haworth systems and to a certain extent in long aeration tanks in the diffused air plants. Obviously a limiting factor is the rate of solution of oxygen in the liquid and this factor determines the ultimate economic rate and conditions for the oxidation of sewage by activated sludge in any particular type of plant. He sums up the experiments by stating:

"(1) The rate of absorption of oxygen by activated sludge depends upon the strength of liquid undergoing purification.

"(2) The rate of purification by activated sludge is probably greater in stronger liquids, if sufficient oxygen is available.

"(3) The stronger and more colloidal the sewage or effluent, the greater is the energy required to dissolve a given quantity of oxygen in the liquid by mechanical aeration."

Construction of plants so that various combinations of conditions can be compared for the particular type of sewage to be dealt with is advised in order that the most economical arrangement can be selected.

Discussion.—In opening the discussion of this paper, Mr. J. H. Garner, President of the Institute of Purification, noted that Dr. Watson's method of determining the amount of dissolved oxygen appeared to be simple and readily applicable to different parts of the plant without expensive apparatus, an advantage over American procedures. He inquired regarding the possibility of adding parts of the raw sewage to various sections of the plant as Haworth had done in a small bio-aeration plant, in other words, instead of regulating the amount of oxygen in different parts of the plant the liquid sewage dose could be so divided.

Captain W. E. Speight (Bolton) stated that the use of sludge reconditioned in the 4 normally operated units for the fifth unit to which double the sewage flow was added in effect opened up the old question as to whether separate reconditioning of sludge was worth while. Personally, he was of the opinion that whatever tank capacity was available in the aeration tanks there must be provided an almost equivalent capacity for sludge reactivation.

Mr. W. D. Scouller (Huddersfield) commenting on the oxygen requirements of sludge as observed by the author stated that he had made this test on Huddersfield sludge by

pumping air continuously through samples in closed bottles, using a specially designed apparatus. The amount of oxygen per gram of sludge was found to be about a quarter of that reported by the dilution method. However, the sludge was of a rather different nature because of the chemical characteristics of the sewage. He questioned the effect on the test using $HgCl_2$ of ferrous iron, if present in the activated sludge. Mr. H. C. Whitehead (Birmingham) confirmed the conclusion regarding the need for excess aeration at the beginning of the treatment period in the channel system and this in fact had been the practice at Birmingham for the past eleven years.

Dr. A. Key (Coventry) in discussing the effect of gas liquors upon the purification process observed that no test on the treatment of gas liquors could be strictly comparable unless a blank test with the same sewage was carried out at the same time. Indications were not lacking that the author's data reflected variations from neglect of this precaution.

Mr. H. Taylor (Stalybridge and Dukinfield) emphasized the experimental stage of the activated sludge process, the possibility of revolutionary improvements that would cheapen the method and the advisability of installing percolating filters.

Further discussion of the paper was had at the North-Eastern Branch Meeting of the Institute of Sewage Purification as reported in *The Surveyor* (January 3, 1936), and to which the author, Dr. Watson, replied.

Regarding the determination of dissolved oxygen in the aeration tanks, the samples were collected by submerging bottles containing 25 cc. of 7.5 per cent $HgCl_2$. On arrival at the laboratory 8 cc. of 20 per cent caustic soda were added and the contents shaken, thereby changing the mercuric chloride to mercuric hydroxide and precipitating the colloidal matter, all of which settled in about ten minutes. The top liquor was then syphoned off in a glass stoppered bottle of about 350 cc. capacity for the D.O. determination by the Winkler method.

Concerning the removal of excess sludge at a half way point in the treatment process to avoid reconditioning of material not later made use of, the point was raised that this procedure would entail the construction of additional settling tanks. The author pointed out that the capacity of final settling tanks would be reduced accordingly.

Another suggestion was to the effect that the revolving cones in the first tanks might be speeded up or altered in depth of submergence to increase reaeration where it was most needed. This latter, the author stated, had been done with the result that twice as much power was used by the first two cones as previously and less than half the power was required by the last three cones resulting in a marked efficiency of treatment for the same amount of power consumption.

J. K. HOSKINS

STRENGTH OF SEWAGE

BY H. BACH

The Surveyor, **89**, 443–44 (March 20, 1936). Comment on paper of the above title as presented by Messrs. Lovett and Garner before the Public Works, Roads and Transport Congress in November, 1935 (cf. this JOURNAL, **8**, 338, 1936).

Dr. Bach makes the point that, aside from the killing of the contained pathogenic bacteria, the only reason for treating sewage is to remove its nuisance bearing properties, and that any other effects produced by the treatment process which have nothing to do with the prevention of nuisance are incidental and waste of energy. Therefore, the strength of sewage is directly proportional to the amount of these nuisance producing properties and the effort required to remove or prevent them. What is needed then, is some rapid method of evaluating the amounts of these substances. Three kinds of contained nuisance are: (1) the sludge, (2) the odor, and (3) the power of dissolved oxygen withdrawal from the water into which sewage is discharged. The strength of sewage, accordingly, should be based on these three factors.

The Sludge Factor.—The removal of suspended solids is the principal factor concerned in nuisance prevention by sludge. However, the mineral and organic solids of sewage are not of equal weight in nuisance production and, therefore, in determining

the strength of sewage this disparity must be given proper weight. For example, if the mineral matter amounts to only 10 per cent of the total weight of suspended matter in a sewage containing 250 p.p.m. of such substances and of which the ash content is 46.5 per cent, then Dr. Bach suggests that the sludge factor in the total strength factor could be computed in some such manner as:

$$\left(\frac{46.5 \times 10}{100} + \frac{53.5 \times 90}{100}\right) 250 = 13{,}200 \quad \text{S.S.U.}$$

or with a sewage of 150 p.p.m. of suspended solids with an ash content of 56.2 per cent, the sludge would account for 6756 S.S.U. (sewage strength units) in the total strength figure.

The Odor Factor.—Only sulphur containing compounds produce objectionable odors about sewage treatment plants contrary to the widespread opinion that nitrogen compounds do so. Decomposing albuminous matters are odorous only to the extent to which they contain sulphur. Nitrogen and phosphorus may contribute some special "flavor" to the sulphur odor and may combine with the sulphur to form an extremely nauseous smell. Conversely even a trace of sulphur contaminating a nitrogen or phosphorus compound may act as an amplifier for an originally slight and non-troublesome odor. Even indol and skatol, if absolutely sulphur free, are odorless. Therefore, sulphur should be determined and serve as the basis for evaluation of the odor factor in determining sewage strength. The manner of computation of this strength factor is not so simple and needs careful study, particularly in the making of any comparison between sulphur contents of different sewages. Dr. Bach makes no specific suggestion on this point.

The Biochemical Oxygen Demand.—Greater difficulties are encountered in estimating this strength factor. Regardless of the great amount of work done on this subject, "there remains much uncertainty as to the application of laboratory small-scale results to the true river conditions which are basically of different character and impossible to imitate closely in routine work." Dr. Bach points out three objections to present methods of B.O.D. determinations: (1) Large magnification of errors inherent in the dilution method by reason of the many-fold dilutions necessary, (2) employment of pure oxygen in the direct method which is never present in nature in such state and (3) the micro-flora and micro-fauna which come into action in the laboratory bottle are derived from sample sewage and not from the river water into which sewage is discharged; in other words, there is no justification for assuming that the course of oxidation in the closed sample bottle seeded with sewage and incubated in the dark is comparable to that of the well aerated stream, exposed to sunlight and supporting a different biological population. For these and other minor reasons, Dr. Bach stresses the need for a dependable procedure for determining the constituents in sewage which cause the oxygen deprivation nuisance.

J. K. HOSKINS

PRETREATMENT OF OCCASIONAL ABNORMAL SEWAGE AS AN ADJUNCT TO THE ACTIVATED SLUDGE PROCESS

BY EDWARD ARDERN AND WILLIAM T. LOCKETT

Paper presented at meeting of the North Western Branch, Institute of Sewage Purification, March 21, 1936.

It frequently happens that on one or two days per week the volume or strength of sewage arriving at a sewage works are greater than on other days, owing to dry weather periods, laundering operations, periodic industrial activities and the like. Such variations create difficulties in treatment plants, both of the filtration and activated sludge types, and unless reserve capacity is provided, result in unsatisfactory effluents. To alleviate such conditions, the authors suggest occasional pretreatment of the incoming sewage by:

1. Chemical dosage,
2. Aeration of the mixture of chemical and sewage for a very brief period, and
3. Short-period settlement.

The results of experiments conducted at the Withington Sewage Works, Manchester, to test out this procedure are presented in this paper.

Comparative Tests Using Aluminium Salts.—Following exploratory coagulating experiments employing ferric chloride, aluminium salts, lime, acid, calcium chloride, etc., which indicated that, having regard to costs, aluminium salts effected the best clarification, the study was confined to these and especially to "Aluminoferric."

Because coagulative properties of aluminium salts are affected somewhat by lowered pH of the liquid under treatment, it was thought desirable to try aluminoferric alone, with acid and with lime. Of the two latter combinations, acid and aluminoferric treatment was preferred, both because of slightly superior results and because the resulting liquors were more suitable for preaeration treatment and for subsequent treatment by activated sludge.

Treatment With Acid and Aluminoferric.—Having determined that best clarification was obtained with sewage at about pH 6.4, acid and aluminoferric were used in combination to obtain approximately this pH value. This was best done by first reducing the methyl-orange alkalinity of the sewage by about one-half with sulphuric acid and subsequently adding sufficient aluminoferric to obtain good clarification. By this procedure the average amount of aluminoferric required was reduced from 40 to 60 p.p.m. over that needed when acid was omitted, and in cases when the sewage was very strong, even larger reductions were made.

Preaeration of Mixtures of Sewage and Chemical.—After addition of the coagulant gentle aeration for 3 to 10 minutes through porous tile was employed to effect better mixing, assist in coagulation of the smaller particles and colloids and perhaps effect some small amount of chemical oxidation of the sewage. Experiments were carried out on sewage treated with aluminoferric alone and in combination with acid. It was determined that by using diffused air at the rate of 12 cu. ft. per sq. ft. of aerated liquid surface per hour, clarification, equal to that obtainable without aeration, could be produced with a reduction of aluminoferric of 40 p.p.m. or more.

Short-period Settlement.—Inasmuch as long settlement periods of the aerated liquids

Effect of Pretreatment (Acid and Aluminoferric, Aeration, Settlement) on Rate of Purification by the Activated Sludge Process

Results in p.p.m.

	Oxygen Absorptions				Nitrogens				B.O.D.
	4 Hrs. at 26.7° C.	3 Min. before Incubation	3 Min. after Incubation	Putrescibility	Ammoniacal	Albuminoid	Nitrous	Nitric	18.3° C. (5-days)
Original raw sewage	108.4	44.0			35.0	10.6			432.2
Sewage aerated for 10 min. and settled for 1/2 hour (*A*)	76.4	32.6			34.0	8.4			
Sewage + acid + 120 p.p.m. aluminoferric aerated for 10 min. and settled for 1/2 hour (*B*)	38.0	14.5			34.0	4.5			
A after 3 hours treatment with activated sludge process	13.8	6.8			19.0	2.0	0.6	3.0	20.0
B after 1 hour treatment with activated sludge process	13.0	6.4	5.6	+	22.0	1.2	0.3	0.3	13.4

later to be treated by activated sludge are not necessary, in the first experiments one hour sedimentation periods were allowed, but later this time was reduced to 30 minutes.

Stabilization of Pretreated Sewage by the Activated Sludge Process.—Experiments indicated that the purification of the above clarified sewage could be effected by activated sludge and diffused air in about one-third the time required to purify to the same degree the original settled sewage. Other experiments, in which the behavior of sludges was observed, after being used for studies of the treatment of clarified sewage, showed that the purifying properties of the activated sludge so used was in no way impaired.

Sludge.—In view of the temporary or intermittent nature of the pretreatment proposed—a matter of 3 to 6 hours on each of two days per week during dry weather periods only—the authors believe that no serious detriment to the sludge such as bulking or low alkalinity will result from the chemical treatment.

Conclusion.—It is concluded that substantial evidence herein presented demonstrates that pretreatment, comprising a combined acid and aluminoferric dosage of sewage, followed by aeration of the mixture of chemicals and sewage with diffused air for a period not exceeding 10 minutes and subsequent short period settlement, constitutes a useful and economic adjunct to the activated sludge process for the treatment of occasional abnormal sewages in periods of prolonged dry weather.

Tabulated data of the various groups of experiments accompany and amplify the paper. The summarized results are shown in Table VII, reproduced herewith.

J. K. Hoskins

THE APPROACH TO SEWAGE CHLORINATION PROBLEMS

By C. Lea

Paper presented at meeting of the Midland Branch, Institute of Sewage Purification, Birmingham, England, February 1, 1936. Reported, with discussion, in *The Surveyor*, 89, 255–56, 321–22 (Feb. 7 and 21, 1936).

The author discusses the subject of sewage chlorination from the viewpoint: granting that chlorine aids in the solution of various difficulties encountered in sewage disposal, what points are to be examined in cases where chlorine is to be employed. Five principal issues are considered.

1. *At what stage of disposal is chlorination required.*—The point of application of chlorine is dependent upon the particular problem to be dealt with and when this point has been properly determined the procedure may prove of direct or indirect value and be beneficial in other respects as well. Thus in the matter of a poor effluent, chlorination might be used to stabilize the organic matters until they reached a larger body of diluting water, but if the crude sewage was arriving at the treatment plant in a septic condition, prechlorination would remedy this condition, eliminate odors and effect a satisfactory effluent as well. Obviously, chlorination of the crude sewage is indicated.

2. *What scale of chlorination is called for?*—The scale of chlorination is a function of the amount necessary to give the desired result and of variations in the rate of application during the period of chlorination. The amount of chlorine is best expressed as consumption per year, while the rate of application is best stated first, as weight of chlorine per day and secondly, weight per hour. In this way data are available concerning the hourly variations of chlorine application corresponding to changing sewage load, daily quantities proportioned to the severity of the difficulty being corrected and the over-all extent of chlorination whether continuous or spasmodic.

3. *Which chlorine agent is preferable?*—Liquid chlorine and bleaching powder are considered. The scale of chlorination, continuity or recurrent treatment, conditions of application, point of chlorination and convenience of usage, storage facilities, ease of application and hazard of use—all are factors to be taken into account. In the great majority of cases liquid chlorine offers very considerable advantage over bleaching powder.

4. *What conditions of application must be observed?*—The manner and rate of application of chlorine are considered. Chlorine is almost invariably added in dilute aqueous solution to the sewage with rapid and efficient mixing provided. Such mixing

is facilitated by proper selection of the point where the solution is introduced, multiple point application or use of some form of solution diffuser. Dilute solutions are essential because the reaction of chlorine with sewage impurities is very rapid and uniform chlorination of the sewage volume is possible only when the disinfecting agent is quickly dispersed throughout the sewage.

The rate of application of chlorine should preferably be based on the dry weather flow, both with respect to volume and strength, because basically, the pollution load is fixed by the population contributing sewage. The chlorine dose should then be applied in proportion to the typical dry weather rate of flow and chlorine demand value for each hour of the typical 24 hour cycle. The pollution load for each hour can then be expressed in terms of the weight of chlorine necessary to satisfy the total chlorine demand, and these 24 figures (in terms of weight of chlorine per hour) are the basis of this proposed system of chlorine application rate. From them the actual rates for the particular location are determined, dependent upon (1) the required percentage of saturation of the chlorine demand and (2) the degree of variation of this percentage to effect the desired result. Having determined these two factors for the range of actual operating conditions, the rate of chlorine application is known for each hour.

5. *What equipment and arrangements are necessary?*—Compactness of equipment, convenience and accuracy of operation and minimum of maintenance care are generally on the side of liquid chlorine apparatus.

In appendices are tabulated a detailed classification of applications of chlorine in sewage disposal, a diagrammatic sketch showing key points of chlorine dosage and physical and chemical characteristics of liquid chlorine and bleaching powder.

Discussion

Mr. Makepeace (Stoke-on-Trent) emphasized the value of prechlorination for control of odor and septicity and the resulting increase of efficiency from treatment processes, but questioned the practical application generally of the author's system of control because of the wide variations in sewage composition and strength from day to day. Experience with prevention of alga growths in effluents had indicated that 1 p.p.m. of chlorine was sufficient, but that effluent used in the condensers of the electric works amounts varying from 0.5 to 1.75 p.p.m. were required to prevent fouling of the tubes. In reply the author observed that the analyses of loading for each of the seven days in the week should be available quite apart from chlorination, although in specific local situations the proposed procedure might be too complicated.

In reply to a question of Mr. Gillard (Heathcote) as to why chlorine prevented the rising of sludge in humus tanks, Mr. Lea suggested that septic action in the bacterial mass was likely retarded and undesirable decomposition prevented.

Mr. Hewitt (Birmingham) maintained that intermittent strong doses of bleaching powder, were preferable to liquid chlorine for control of septic conditions in limited areas or at special times and that moreover the normal bacteria of sewage were less affected. The author replied that preferably all the sewage should be chlorinated to avoid rapid decomposition of deposited particles.

Dr. Key (Coventry) noted omission of mention of amounts of chlorine generally required, which was explained on the ground that three papers dealing with this phase of research at Sheffield had been published. Dr. Key also questioned the statement that septicity in crude sewage impaired the oxidation capacity of filters or activated sludge plants in view of published experiments showing that some biological purification of sewage was effected in settling tanks. Mr. Lea took exception to these published conclusions of Mr. O'Shaughnessy because the character of the tank effluent was judged on the oxygen absorbed and therefore misleading.

In reply to an inquiry from Mr. Price (Birmingham) as to how far chlorine was an ultimate solution to the disposal of sewage the author distinguished clearly between the temporary stabilization of effluents as effected by chlorination as contrasted with oxidation. The paradox of partially sterilizing stale sewage subsequently to be treated biologically was explained on the ground that different bacterial flora were involved in such processes from those predominating in septic sewage liquors.

Mr. Ward (Shrewsbury) described the benefits derived from chlorination of the crude sewage previous to land treatment. He considered that the purpose of chlorination of sewage was to retard putrifaction and not effect complete sterilization.

J. K. HOSKINS

NEW METHOD OF SLUDGE DISPOSAL

ANON

The Surveyor, 89, 418C (March 13, 1936)

The Porteous process is based on the fact that heat and pressure applied to sewage sludge from an ordinary primary settling tank cause coagulation, settlement and purification within a brief period. Sludge is heated to a high temperature under steam pressure and then dewatered in a pressure filter. Experimental plants have been installed at the Wandle Valley sewage works at Halifax, and at Sheffield and Bradford. At Halifax, humus is mixed with activated sludge and then dewatered by this process with the object of obtaining a fertilizer.

At Wandle Valley the experimental plant consists of a sludge boiler half sunk in a furnace chamber built of steel plates lined with fireclay slabs. Pressure in the boiler is maintained by compressed air. The sludge containing 95 per cent water is heated under pressure, then expelled into a decanter which also acts as an air receiver for the filter pressing process. The sludge is dewatered in an ordinary standard press. The filter cakes are normally ¾ inch thick, contain 40 per cent water and are produced in 10 minutes pressing time. They are hard, and have no unpleasant odor. The supernatant liquor from the decanter amounts to about 65 per cent of the total sludge volume, is of a brownish yellow color free from odor when warm or cold. Experimental work is in progress to determine the strength of this and the press liquids and the possibilities of their purification by filtration.

Interesting details of design of large plants relate to economies through use of the press cake as fuel for steam and drying purposes, manufacture of fertilizer and treatment of the supernatant liquors from the decanters and sludge presses.

J. K. HOSKINS

STUDIES ON THE SURVIVAL OF B. TYPHOSUS IN SURFACE WATERS AND SEWAGE

BY H. HEUKELEKIAN AND H. B. SCHULHOFF

New Jersey Agricultural Experiment Station Bulletin No. 589, New Brunswick, N. J.

The survival of B. typhosus in various artificially infected substrates was studied, using brilliant green agar for the enumeration of the numbers. This medium did not inhibit B. typhosus, but it was not entirely satisfactory because it did not produce distinctly characteristic colonies with all strains of B. typhosus used and because it failed to inhibit to any great extent the numerous other organisms encountered in polluted water and sewage.

The investigation showed that there was a rapid decrease in numbers of B. typhosus in polluted water and sewage. The rate of decrease is greatly influenced by temperature, being greater at higher temperatures.

The addition of food material in general may be followed by an increase in numbers of B. typhosus. The rise is followed by a very rapid decrease so that the addition of food does not apparently increase the survival time.

The survival time of B. typhosus is decreased by aeration, decreased by B. coli in the presence of food, decreased by certain industrial wastes in sewage and increased by the presence of flavo-bacterium.

With the technique employed, no successful isolation of B. typhosus was made from 0.1 c.c. samples of various municipal sewages.

In activated sludge mixtures there is an initial increase in numbers of B. typhosus followed by a rapid decrease. During anaerobic digestion of sewage solids, the numbers of these organisms decrease rapidly.

The percentage reduction of B. typhosus in artificially infected sewage is of the same magnitude as the normal sewage flora when the sewage is partially chlorinated. With 25 per cent of the chlorine demand satisfied the reduction in numbers of B. typhosus was over 99 per cent in 10 minutes contact time.

C. C. RUCHHOFT

THE USE OF ROTTED LEAVES FOR PROMOTING DIGESTION OF RAW SEWAGE SLUDGE AND INDUSTRIAL WASTES

BY PROF. DR.-ING. C. REICHLE AND DR. P. SANDER

Gesundh.-Ing., **58**, 558 (1935)

A number of years ago it was observed that leaves decomposed very rapidly in a pond which received sewage. Experiments showed that a mixture of rotted leaves and sewage sludge digested more rapidly than sewage sludge alone. Last year an opportunity was offered to test the use of rotted leaves on a large scale at a municipal treatment plant which consisted of three separate sludge digestion tanks, each of 79,250 gallons capacity. Acid digestion set in and after liming, digestion stopped. Three loads of rotted leaves, or 1 to 2 per cent of the tank capacity, were added to one tank without stirring and within a few days the sludge began to produce gas. This action became so strong that the tanks foamed. The other two tanks were treated in a similar manner with the result that the difficulties were overcome. The digested sludge dried rapidly on drying beds without any nuisance from odor.

Before the leaf falls the carbohydrates and proteins pass into the stem and the leaf itself consists mainly of cellulose. The digestion of wet leaves on the ground is accomplished mainly by bacterial action. The bacteria, which are spore formers, may survive over many years and are widely distributed.

In these experiments unwashed, mixed fallen leaves were used. It is preferable to use those with stems and ribs which are not too strong.

Leaves added to cooker liquor from a sulphite cellulose plant started digestion of the mixture. At the end of the hydrogen sulphide formation the mixed liquor was strongly colored and had a considerable oxygen consumed value. Experiments with dairy wastes showed that strong digestion appeared within three or four days after addition of the leaves. The reaction at the beginning of hydrogen sulphide formation was distinctly acid but the mixture gradually became alkaline.

G. P. EDWARDS

ARTIFICIAL LAKES AS CLARIFICATION PLANTS

BY DR.-ING. GEORG MAHR

Gesundh.-Ing., **58**, 711 (1935)

Hengstey Lake, completed in 1927, was built to hold back, during low and average flows, the large amount of iron sludge which the Lenne River discharged into the Ruhr. It was soon evident that the lake effected a valuable biological purification.

The organic matter in a river is oxidized by small organisms and converted into stable mineral compounds. The decomposition, which continues for several weeks, progresses rapidly at first and gradually diminishes. After about 20 days the carbonaceous material is decomposed. The decomposition processes are affected by the temperature, as the total oxygen demand is somewhat less at lower than at higher temperatures. For example, if the oxygen demand at 20° C. is assumed to be 100 per cent, at 10° C. it is only 80 per cent and at 30° C., 120 per cent. The speed of decomposition also increases with the temperature. This means that, on the first day, at 10° C. about 12 per cent of

the total demand is satisfied, at 20° C. about 20 per cent, and at 30° C. about 30 per cent. A measure of the oxygen demand of the river can be obtained by combining these two relations. If the value at 20° C. is assumed to be 100 per cent, then on the first day, at 10° C., only $0.8 \times 12/20$ or about 50 per cent of the oxygen demand is satisfied and at 30° C. $1.2 \times 30/20$ or about 180 per cent of the oxygen demand is satisfied.

Streeter has proved that the decomposition of polluting substances in a large river follows closely the same laws that govern the B.O.D. curve.

Temperature plays a large part in the decomposition of sewage sludge which has been deposited on river bottoms. With constant temperature, the oxygen demand of the entire sludge bed is not increased over a certain fixed value, as an equilibrium is set up. The daily oxygen demand of the deposited sludge is, therefore, about equivalent to the 20-day demand of the sludge which is added daily. This equilibrium at 20° C. is reached after about 20 to 30 days and at lower temperatures after longer periods.

When the temperature changes, a new equilibrium is set up. With a sudden rise in temperature, for example, from 15° to 25° C., the daily oxygen demand almost doubles and then gradually decreases to the ordinary value. If the sludge begins to gas, the oxygen demand may suddenly increase to such a point that the oxygen of the stream may be completely exhausted.

Sludge deposits may also result from settled sewgae as the non-settleable solids coalesce in the water and precipitate. Occasionally sludge deposits may form from algae and fungi growths.

Oxygen is required for the oxidation of both the soluble and the suspended solids of the sewage and in a lake the oxygen demand of the soluble substances would depend on the detention period. The entire demand of the settled solids also must be satisfied. About 30 per cent of the oxygen demand of a settled domestic sewage results from the suspended solids and 70 per cent from the soluble substances. A lake must satisfy the 30 per cent oxygen demand from the suspended solids and such part of the 70 per cent as corresponds to the detention period in the lake. At 20° C., about 20 per cent of the total oxygen demand is exerted on the first day, 36 per cent on the second day and 50 per cent on the third day. With a one-day detention period the oxygen demand would be $30 + (0.7 \times 20)$ or 44 per cent and with a two-day detention period. $30 + (0.7 \times 36)$ or 55 per cent. The first part of the equation represents the oxygen demand of the suspended solids and the second part, that of the soluble matter. It is important to note that, with detention periods of less than two days, most of the oxygen demand comes from the suspended solids. If raw sewage were discharged into a lake, not 30 per cent but perhaps 40 or 50 per cent of the entire oxygen demand would be caused by the suspended matter.

Dissolved oxygen in water is obtained from tributary waters and by absorption from the air. The amount obtained from green plants is uncertain and may be disregarded. Let us assume that a fairly pure river, with a flow of Q cubic meters per second, discharges into a lake and that an amount of sewage of q cubic meters per second flows into the river just before it empties into the lake. The river water may contain a large amount of oxygen and can give up part of this supply to the lake. The water as it leaves the lake must contain some oxygen, although it may be a very small amount if the water is aerated by passing over a dam. The amount of oxygen, b grams per cubic meter, which the lake can obtain from the river, varies according to local conditions but is seldom greater than 4 to 5 grams per cubic meter. No additional oxygen can be expected from the sewage.

If B is the average width, T the average depth of the lake and v the velocity of flow through the lake, then

$$Q + q = BTv.$$

The surface of lake water passing a point in one second is

$$Bv = \frac{Q + q}{T}.$$

If a grams per square meter per day is the oxygen absorbed from a unit surface, then

the lake surface takes up

$$\frac{a\,(Q+q)}{T} \text{ grams of oxygen in a second.}$$

In general, a is, at the most, 3 to 4 grams per square meter per day.

If the detention period of the water in the lake is Z (measured in days) the lake obtains the following amount of oxygen, S, per second:

$$S = Qb + \frac{a\,(Q+q)}{T} Z.$$

If a dilution factor $\frac{q}{Q+q} = \frac{1}{n}$ or $\frac{q}{Q} = \frac{1}{n-1}$ is introduced into the above equation, the oxygen absorbed, S, per second is

$$S = Q\,(b + \frac{1}{n-1} \times Z \times \frac{a}{T}).$$

The first part inside the bracket represents the oxygen obtained from the river water and the second part that absorbed from the air. In lakes more oxygen is usually obtained from the tributary water than by absorption.

Example.—An artificial lake has a pure water flow of $Q = 5$ cubic meters per second and a sewage of addition of $q = 1$ cubic meter per second. The average water depth of the lake is 2.5 meters. The oxygen absorbed at the surface is $a = 4$ grams per square meter per day and the amount received from the tributary water is $b = 4$ grams per cubic meter. The lake is relatively small and has a detention period of only half a day. The oxygen avaliable is

$$5\,(4 + \frac{6}{5} \times \frac{1}{2} \times \frac{4}{2.5}) = \text{about } .25 \text{ gram per second.}$$

The sewage which has been well settled has a total (20-day) B.O.D. of 300 grams per cubic meter and the oxygen required by the sewage is

$$(0.30 + \tfrac{1}{2} \times 0.14)\ 300 \times 1 = 111 \text{ grams per second.}$$

If, in addition, the river water had a B.O.D. of 10 grams per cubic meter, the total demand would be increased about $(0.30 + 0.07)\ 10 \times 5 = 19$ to 130 grams per second. The lake, however, cannot produce this much oxygen and so would become septic. If the sewage were not only settled, but also filtered, then the oxygen required would only be about

$$\tfrac{1}{2} \times 0.14 \times 300 \times 1 = 21 \text{ grams per second.}$$

It is evident that in a polluted lake the very fine, suspended solids must be removed as completely as possible. At present, the filtration of sewage is unusual but experiments at the Wupperverband have shown favorable results and have indicated beneficial effects on the river.

American workers have found that in moderately large and deep rivers the natural decomposition proceeds at about the same rate as in a glass flask in the laboratory. Our experience has been that the decomposition takes place more rapidly in small shallow rivers. The difference is obviously explained by the fact that, in shallow channels, microorganisms aid in the decomposition of organic matter and oxygen is more quickly replenished by absorption and by the action of green plants.

G. P. Edwards

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VOM WASSER IX

Yearbook of the Water and Sewage Group of the German Chemical Society and the Sewage Group of the German Construction Society

Sewage Section. 96 pages. Paper, 5 RM; Bound, 8 RM.

Verlag Chemie, G.M.B.H., Berlin 35

This ninth volume of "Vom Wasser" consists mainly of papers presented in April, 1935, at the Leipzig meeting of the German Chemical Society and the German Construction Society. The symposium stressed consideration of the possibility of recovering values from sewage, consequently the papers deal with the use of sewage for irrigation, the growth of fish in sewage effluents, the recovery of solids from industrial effluents (coal) and the recovery of grease from sewage.

There are four papers, by Krenz of Dülmen, Schonnopp, Weise and Haase of Berlin, on the spraying of sewage on land by means of high-pressure revolving nozzles. The installation at Delitzsch is described, also experimental investigations at the Stahnsdorf and Wassmannsdorf plants in Berlin. The fertilizing constituents of the applied sewage have produced great increases in the growth of crops on the sprinkled areas. The sprays are built with radii from 30 to 120 m. and the dosage is said to average 25 cm. per year. As the capacity amounts only to 40 to 60 persons per hectare (2.47 acres) it is difficult to consider this proposal seriously as a means of disposal of sewage.

The Munich fish ponds are described in detail by A. Schillinger. They cover 575 acres and have a detention period of about two days. The sewage is well clarified and diluted with approximately three volumes of pure water. The production of fish averages about 276,000 lb. per year, or 475 lb. per acre per year.

Dr. Heilmann of Berlin has an interesting paper on the amount, character and recovery of grease from German sewage.

Dr. H. Haupt, of Bautzen, who is so well known for his consulting work on industrial wastes and boiler waters, discusses the possibilities of recovery of products from the wastes of such industries as sugar, starch, paper, textiles, breweries, etc. It is disappointing to note that sulphite waste is still as much of a problem in Germany as in the United States.

The recovery of coal sludge and phenol, in the coal and coke plants of the Ruhr District, is discussed by Director A. Wiegmann of Essen.

Dr. van der Leeden, of Neuminster, closes the volume with a paper on tannery and slaughterhouse wastes.

The note of optimism that characterizes this volume, with reference to recovery of values from sewage and industrial wastes, is hardly justifiable by the account of actual progress in Germany. However, the papers are stimulating and deserve study by American readers.

F. W. MOHLMAN

534